

When the Enemy Has Our Eyes

by

Cynthia A. S. McKinley

INTRODUCTION

On January 17, 1991, the United States entered a war that turned the military space community upside down. Until then, the military space community's focus was locked on the strategic concepts that were developed and refined throughout the Cold War. The Gulf War expanded that focus to include the operational and tactical levels of warfare. This change is causing space strategists to consider a broader spectrum of space functions for enhancement, and perhaps most importantly a broader spectrum of measures for space control.

In addition to this expanded focus, the reconnaissance satellite playing field continues to undergo significant changes. During all but a few years of the Cold War, there were only two players in the spy satellite game. This was slowly changing toward the end of the Cold War. At the time of its invasion of Kuwait, the Iraqi military was receiving military support from the Soviets and purchasing satellite imagery from the French. Soon after the invasion, the Soviets joined many other nations in their condemnation of the Iraqi government's behavior and the French refused to sell imagery products. This left the United States in possession of a temporary monopoly on the ability to routinely and unobtrusively probe the enemy's battlefield with highly accurate reconnaissance satellites. Those space assets revealed volumes about the Iraqi capabilities and intentions for battle. The United States assured its Gulf War victory through the combined strengths of its overwhelming offensive power and its unprecedented knowledge

19970923 095

DISSEMINATION STATEMENT A

Approved for public release
Distribution Unlimited

New Text Document.txt

18 SEPTEMBER 97

This paper was downloaded from the Internet.

Distribution Statement A: Approved for public release;
distribution is unlimited.

POC: SCHOOL OF ADVANCED AEROSPACE STUDIES
AIR UNIVERSITY
MAXWELL AFB AL 36112

22-

of the battlefield. As the world watched this display, it quickly learned that future warfare success may require a similar illumination of the battlefield.

As the lessons of the Gulf War are being internalized, national and international actors are endeavoring to participate on the high ground of space reconnaissance. The movement to gain access to high quality satellite photo-reconnaissance data has turned into a stampede in only four years. For a nation such as France that has been in the photo-reconnaissance business for nearly a decade, this stampede is enabling it to move a rung higher on the international competitive ladder. For Russia it represents an opportunity to regain stature and much needed wealth. It also shows the world that Russia remains a superpower in the space business, one of the most prestigious of all fields for national pride.

Combining the modified space operations focus and the multi-polar space systems playing field, the next war is likely to differ from the Gulf War. Indeed, in the next war, it is likely that the enemy will have our eyes. The United States must be prepared to pursue active space control measures to deny the enemy's access to critical reconnaissance information. However, this problem cannot be solved in a vacuum; the space control mission does not stand alone. It is shrouded in nearly forty years of history. Furthermore, space control must be achievable within the constraints of current and future international environments. Space control's history and environments need to be unraveled to reach an understanding of how the United States can execute space control in the contemporary world. This monograph will provide information that may be helpful to future space strategists and decision-makers in determining how to accomplish this mission.

This monograph uses research, analysis, and synthesis to take the reader through the study's three subdivisions of the past, the future, and the challenge. Each subdivision offers unique information in an effort to help the reader understand the space community's focus during the Cold War and how that is changing, and to place the space control mission in its context before attempting to offer space control methods.

Part I, The Past, recounts the rise of strategic space intelligence, explains the revolution brought about by digital image processing technology, and elaborates on the changes resulting from the employment of space's strategic assets in modern theater warfare. Part II focuses on the future by speculating on the forms of modern warfare and imagery's potential role in them. Part III, Meeting the Challenge, discusses the space control mission and various denial methods that will be considered for employment against the commercial reconnaissance system.

PART ONE: THE PAST

The Rise of Strategic Space Intelligence

Strategic space intelligence is one of the first products of the Cold War. Today, it remains one of the United States military's most important assets. Its formative years were molded by three themes: competition to lead the nation's space program, the strategic nuclear threat posed by the Soviet Union; and the technological challenges of new frontier.

Planting the Seed

The evolution of America's space-based reconnaissance systems traces to the conceptual seed planted by Wernher von Braun in May 1945. Von Braun, developer of the V-1 and V-2 rockets for Nazi Germany, is credited with reuniting Adolph Hitler's Peenemuende rocket team to form the nucleus of America's civilian and military space programs. Using the knowledge he gained from his rocketry work, he provided a report to the United States Army that examined German views on the potential of rocket launched satellites.¹ This seed quickly grew into an inter- and intra-service rivalry that drove the Army, Navy, and Army Air Force into a competition to become the agency responsible for future military satellite vehicles. By October 1945, the Navy had published its views on the use of satellites. Already behind the power curve, Major General Curtis LeMay, Director of Research and Development for the Army Air Force, commissioned the RAND Corporation to conduct a three-week crash study on the feasibility of space satellites.² General LeMay and General Carl Spaatz, Commanding General of the Army Air Force, quickly realized that this new frontier was another mission area that could help

justify the formation of an independent Air Force.³ Thus, Army Air Force involvement, along with the intense inter-service rivalries, encouraged this little understood domain to become a fertile arena for the competitive exchange of ideas.

During the ensuing years the scientific and military communities studied the feasibility and operability of potential satellite systems. With both strong proponents and opponents arguing the potentials and limitations of such technological challenges, the research and development path was by no means smooth. Despite these difficulties, by 1951, the Air Force was able to define its requirements for an operational satellite system. There were three primary requirements for an Air Force satellite system: (1) an ability to produce photography of sufficient quality to enable trained interpreters to identify objects such as harbors, airfields, oil storage areas, large residential areas, and industrial areas; (2) a capability to provide continuous daytime observation of the Soviet Union, cover its landmass in a matter of weeks, and record the data collected; and (3) an ability to produce a quality photographic product suitable for the revision of aeronautical charts and maps.⁴

During these early days of concept exploration and requirements definition, many agencies worked independently without the benefit of oversight. This changed in December 1953 when the Air Research and Development Center gathered many of the proliferating aspects of the research and development groups into a single project entitled Project 409-40. Project 409-40's mandate was to provide the first operational imagery satellite system. The prospective satellite system for this project was given the weapons system designation of WS-117L.⁵ The satellite was to be based on state of the art television and videotape recorder technology. However, its engineers soon realized that the 144 foot resolution that this system could provide was inadequate for the task. This

technological problem fueled the skepticism and hostility of many Department of Defense personnel who doubted that such systems could ever be of value. But the believers persisted, due in part to President Eisenhower's vision and his determination to gain information on the Soviet Union's nuclear weapons delivery vehicle capabilities.

The Technological Capabilities Panel formed by President Eisenhower in 1954 provided a briefing in February 1955 on the options for obtaining intelligence data about the Soviet Union. The Panel included such notables as Massachusetts Institute of Technology President James R. Killian, Jr., Polaroid founder Edwin H. Land, Harvard astronomer James G. Baker, and Washington University's Joseph W. Kennedy.⁶ These academic and industry leaders advised President Eisenhower that there were three options for gaining photo-reconnaissance data on the Soviet Union: build strategic reconnaissance aircraft, attempt balloon reconnaissance, or develop a satellite reconnaissance system.⁷ Supporters of satellite systems hoped the committee would recommend the satellite solution as the top priority, but the committee's official recommendation was to build strategic reconnaissance aircraft.

Not swayed by the committee's focus on near-term solutions, the Air Force quickly issued General Operational Requirement number 80. Issued less than a month after the committee's report to the President, this document established an official requirement for an advanced reconnaissance satellite.⁸ By November 1955, the basic technical tasks were defined and approved and the project was given the code name PIED PIPER. PIED PIPER's goals were to provide a complete satellite reconnaissance system, including ground facilities for analyzing and disseminating imagery, and to be fully operational by the third quarter of 1963. Three corporations competed for the rights to

build this visionary project: Radio Corporation of America, Glenn L. Martin, and Lockheed Aircraft.⁹ By October of 1956, the Air Force had made the contract award decision. Lockheed was notified to proceed with its development of the Advanced Reconnaissance Satellite as well as the upper stage Agena vehicle that would propel the satellite into low earth orbit.¹⁰

The Threat: Soviet Strategic Nuclear Attack

Work on the WS-117L project progressed at a steady pace until the Soviets shocked America with their launch of Sputnik on October 4, 1957. This unsettling event shook the foundations of the military and scientific communities, the government, and the population of the United States, and helped consolidate the communities' work toward meeting the challenge and threat posed by the Soviets. On January 22, 1958, the National Security Council issued Directive number 1846, assigning the highest priority status to the development of an operational reconnaissance satellite.

By February 1958, space experts were briefing President Eisenhower on the two potential imagery acquisition methods using space platforms. One was the original method proposed in Project 409-40, that is, using a film-scanning technique, and the other used a film and satellite recovery method. President Eisenhower decided that the film and satellite recovery system offered hope of immediate payoffs and decided to assign program development responsibilities to the Central Intelligence Agency. Several factors led to these decisions. He was concerned that the PIED PIPER non-recoverable technology would not yield an operable satellite as quickly as needed; was not enthusiastic about an Army role in space; was concerned about security failings; and had confidence in the CIA's ability to lead the program because of its experience with the secret development of

the U-2 airborne imagery collection system. Thus, at the February 1958 meeting, President Eisenhower approved the infamous CORONA project. The CORONA system was designed to quickly provide an operational spy satellite through development of a recoverable capsule system. The CIA's marching orders were to have the system ready for use by the spring of 1959.¹¹

The cover for the CORONA program was the DISCOVERER satellite program. Additionally, the government established a military research and development agency, the Advanced Research Projects Agency, to handle the public aspects of the project. The portions of the WS-117L project that pertained to reconnaissance satellites were canceled and restarted in the highly secretive world of the CIA under the CORONA cover. The Air Force was tasked only with the responsibility of testing techniques for recovery of a capsule ejected from an orbiting satellite. After a February 1959 launch failure and the Soviet recovery of a capsule launched in April 1959, the CIA's CORONA project met with success in 1960. It was in that year that American space experts successfully launched and recovered two film capsules. By 1961, the CIA's film recovery program was stable and providing regular imagery of the Soviet Union.

Using state of the art equipment, the CIA secretly acquired imagery of great military significance throughout the 1960s. The imagery met the specifications laid out in 1951 by the Air Force, and more importantly, could identify exactly what the Soviets were accomplishing in the strategic nuclear arena. This program and its follow-ons were deemed highly successful at providing high quality photographic imagery for the United States until the program was superseded in October 1984.

Film-Based Solutions Today; Electro-Optics Tomorrow

The decision to pursue the film-based recovery system was a prudent decision considering the technological capabilities of electro-optics in the late 1950s. Eventually however, electro-optic technology would evolve to the point where its product would match that of the film-based systems and surpass the latter's ability to provide near real-time intelligence data. Believing this to be true, the many proponents of electro-optical systems continued to develop and refine this emerging technology.

Although it may not have been viewed this way in the 1960s, what appears to have emerged is a dual-track technology progression. One track was the logical short term solution and the other was the long term method for providing Cold War strategic intelligence. Figure 1 provides an analysis and synopsis of this dual-track technology progression.

Despite official cancellation of all Air Force satellite activities except recovery techniques, work on the on-board film scanning system continued to challenge its proponents. The earliest available evidence that anyone was pursuing digital processing technologies for military application appears in a 1957 report. In its report to the Air Force, Radio Corporation of America recommended and the Air Force accepted the idea of a combined film and digital based system.¹² This plan called for using a film scanning technique in which a conventional camera photographed the target and the film was developed on board. Once developed, the film was scanned with a fine-light beam and the resulting signal was sent to a ground receiving station. The ground station translated the signal back into an image. The Air Force program that used this technology was the SAMOS program.¹³

The Air Force's SAMOS program launched its first satellite in October 1960. After achieving only two successful launches in its five attempts between 1960 and 1962, this program was deemed a failure and officially canceled in 1962. However, this cancellation may have been an attempt to divert the notice of the Soviets and others. SAMOS-5, the last of the SAMOS launches, was the most successful and provided imagery resolution in the 30 meter range, not much worse than that provided by the multi-spectral imagers of today's SPOT¹⁴ system.¹⁵ Although officially canceled, its technological advancements reappeared that same year in the CIA's second generation program code named KEYHOLE. While some of the KEYHOLE satellites continued to exploit the successful film-based system,¹⁶ others were designed to use the film scanning technique. Although never launched, some development work occurred through the KH-5 Army mapping and the KH-6 Tallinn mission satellites.¹⁷

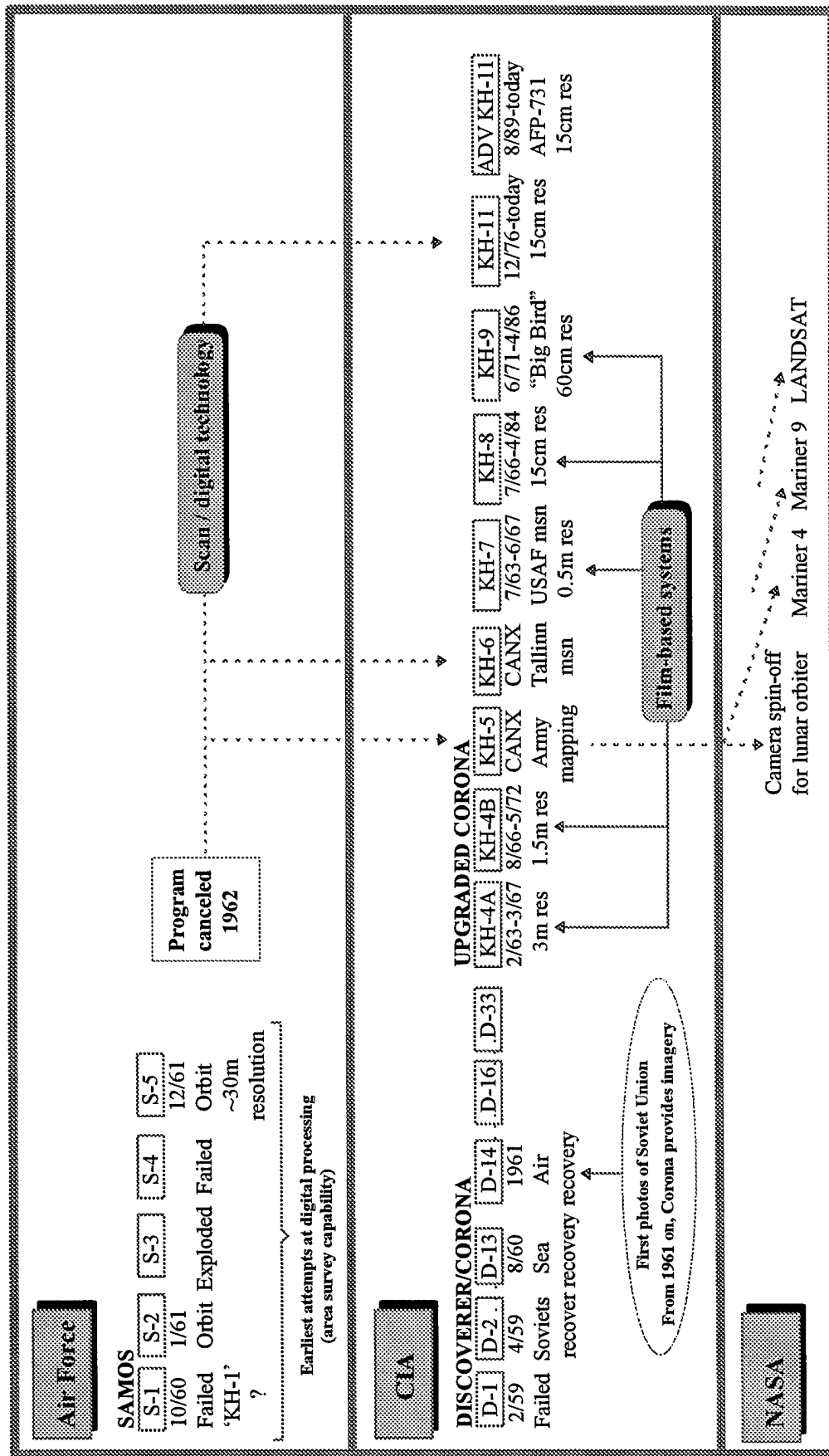


Figure 1: The Dual Track Technology Progression (Film-Based & Digital Processing)¹⁸

It appears that the first successful use of low quality digital image processing technology occurred at the National Aeronautics and Space Administration. NASA used the KH-5 film scanning camera on its lunar orbiters, Ranger and Surveyor, in the mid-1960s and later in Mariner 4, Mariner 9, and LANDSAT.¹⁹ When Mariner 4 was launched in 1964, it was advertised as being the first all digital imaging system. Seven years later, Mars became the first planet to be mapped entirely from digital remotely sensed data. The use of digital image processing technology for lunar and planetary exploration continued throughout the 1970s with the launches of Pioneer, Viking, and Voyager series spacecraft. By 1972, NASA was ready to apply the technology to earth remote sensing and on July 23, launched the first LANDSAT satellite. LANDSAT was the first American spacecraft to provide multi-spectral imagery.²⁰

By 1976, with fifteen years of space reconnaissance work behind them, America's imagery network was well established and performing well. It was about to become even better. America's space strategists and scientists were about to elevate the satellite imagery program to an advanced technological plateau. While they comfortably sat on the successes of the film-based imagery systems, some analysts probably realized that NASA's digital imaging systems were but small indicators of the CIA's spy satellite work. It was in her bicentennial year that America succeeded in turning the tables on the Soviet Union. In 1976, America rattled the bear's cage by launching the first KH-11 reconnaissance satellite into its near-polar orbit.

The Digital Imagery Revolution

By 1976, the United States and the Soviet Union were experts at the orbital cat and mouse game of satellite reconnaissance. Both nations used film and satellite recovery systems and had routinized their operational procedures. Despite eloquent protests about spy satellites' violation of national sovereignty, both nations acquiesced to the Open Skies policy²¹ for spy satellites. Both nations realized that these systems provided insights into each other's strategic nuclear activities and thus provided some stability in a very dangerous world.²² Soon after celebrating its 200th anniversary, the United States launched a satellite that revolutionized the photo-reconnaissance business and set the stage for its later use in operational and tactical level warfare. For a few short years, the United States operated alone on this high plateau of technological achievement. However, achievement breeds imitation. The Soviet Union and France soon developed similar systems.

Charge Coupled Devices and Computers: Keys to the KH-11

The KH-11 satellite launched on December 19, 1976, was the first photo-reconnaissance satellite to provide high quality non-film-based imagery. The KH-11's real-time sensing systems²³ and high resolution charge coupled device (CCD) cameras²⁴ enable it to distinguish military from civilian personnel. The infrared and multi-spectral sensing devices of the latest models can locate missiles, trains and missile launchers by day or night, and can distinguish camouflage and artificial vegetation from living plants and trees. Space analyst Jeffrey Richelson claims the KH-11 is capable of 15 centimeter²⁵ resolution using a mirror of at least two to three meters diameter (similar to the Hubble Space Telescope).²⁶ The launch of the KH-11 was a significant milestone in the

achievement of space-based imagery products and represented a personal triumph for Leslie Dirks, the CIA's Deputy Director of Science and Technology.

The KH-11's roots reach back to RAND's 1945 concept of a television-type imagery return system.²⁷ Realizing that the technology of the 1950s and 1960s was inadequate to provide the near real-time data that the national reconnaissance community wanted, Dirks continued to believe it would be available in the future. The breakthrough technology by which the KH-11 became capable of collecting and transmitting imagery in real-time lay in its use of the CCD. The CCD originated at Bell Telephone Laboratories in the late 1960s when two researchers, William S. Boyle and George E. Smith, sought to invent a new type of memory circuit.²⁸

For those in the government whom had access to the revolutionary digital imagery provided by the KH-11, its significance was obvious and immediate. Although initially limited to data collection for only a few hours each day,²⁹ a system that could provide near real-time images of the earth gave decision-makers a near instantaneous ability to see exactly what the adversary was doing. For the analysts, this new system released them from the light table and stereoscope.³⁰ With digital image processing technology, the analysts began using the much more flexible and dynamic medium of computers.

Using computers, the analysts recalled imagery from the database and manipulated it through a variety of viewing options. For example, the analysts changed the contrast to increase the visibility of objects that were in shadows, obscured by haze or thin cloud cover, or photographed with too much or too little exposure.³¹ Computers began performing the task of object detection. Changes in a particular target area were determined using a technique known as electronic optical-subtraction. Among the other

computer advantages were the ability to improve the image resolution and the ability to delete distortions inherent in photographic systems.³²

The American Monopoly

From 1976 until 1982, the United States was the only nation utilizing digital image processing technology in its reconnaissance satellites. Combining this technology with its older film-recovery systems and airborne platforms such as the U-2 and SR-71, America's ability to acquire strategic intelligence surpassed that of any other nation.³³ A few of the important bits of strategic intelligence data that these systems provided were nuclear weapons developments and tests, adherence to arms control agreements, locations of strategic and tactical aircraft, troop deployments, and military construction.

The United States' monopoly on digital image processing technology crumbled in 1982 when the Soviets launched their fifth-generation reconnaissance system. With this system, the Soviets followed the Americans in liberating themselves from reliance upon the film-recovery system. Their fifth-generation satellite offers 20 centimeter resolution, nearly the same as that of the KH-11.³⁴ The speed with which the Soviets were able to bridge the technology gap with the Americans is probably explained by the several thefts of KH-11 documents that occurred shortly after the first KH-11 was launched.³⁵

Several copies of the specifications for the KH-11 system appeared in the Soviet Union in the late 1970s. The first arrived through William Kampiles, a Greek-American who began working for the CIA in 1977.³⁶ Unhappy with his pay, tedious work, and unglamorous watch tours, he resigned from the CIA after less than a year and journeyed to Greece in 1978. Packed in his suitcase was copy number 155 of the *KH-11 System Technical Manual*.³⁷ Once in Greece, Kampiles approached a Soviet Embassy official and

offered to provide American intelligence documents. Although he requested \$10,000 for the KH-11 document, Kampiles received a mere \$3,000 for the technical manual that opened the door to one of America's greatest technological achievements.³⁸

Aided by America's technology secrets, the Soviets were ready to launch their first digital imagery satellite system on December 28, 1982.³⁹ Analysts know little about this first all-digital Soviet satellite. In fact, some analysts still question whether or not it actually represents the Soviets' first attempt to use digital processing. The Soviets' first undisputed use of digital technology occurred with its launch of Cosmos 1552 on May 14, 1984. Collection systems have not detected signals from this or subsequent fifth-generation satellites, so analysts believe that the data is retrieved via Molniya⁴⁰ or geosynchronous communications satellite links. Russia continues to use its Generation 5 satellites today and has apparently developed a Generation 6 follow-on to this initial successful use of digital processing technology.

The French Go Commercial

France, one of the five acknowledged nuclear powers, joined the digital image processing world only four years after the Soviets. Unlike its American and Soviet predecessors, French entry into this domain occurred in the commercial marketplace. The French government began the SPOT program in 1978 and first exploited digital image processing technology satellites with its launch of SPOT-1 in 1986. The SPOT system does not offer the high resolution of its military counterparts; it provides 20 meter multi-spectral and 10 meter panchromatic resolution imagery. Also unlike its American and Soviet counterparts, the French government did not attempt to underwrite all of SPOT's developmental costs. From its inception, national and international governmental and

private firms have participated in the program. Over a dozen French, Belgian, and Swedish agencies had a stake in SPOT-1's success. Today, the expansive SPOT Imagery Corporation provides imagery to customers on every continent.

The French entry into the commercial exploitation of digital image processing technology could have signaled the beginning of the transformation of photo-reconnaissance imagery to operational and tactical use, but it wasn't until the United States needed such data in a regional war that the military space community began to realize that a fundamental transformation was underway.

Transformation:

Strategic Intelligence in Theater Warfare

Throughout the Cold War, space-based strategic intelligence enhanced global stability by enabling governments to monitor crises and watch for remote nuclear weapons tests.⁴¹ Observation satellites monitored possible threats to the regimes established by the 1963 Limited Test Ban Treaty, the 1970 Nuclear Non-Proliferation Treaty, and the 1972 Strategic Arms Limitation Treaty. They played an active role in monitoring the 1971 Indian-Pakistani war, the 1973 Arab-Israeli war, and the Iran-Iraq war of the 1980s. Utilizing their strategic eyes, the superpowers kept watch over turmoil in many theaters.

However, it wasn't until the Gulf War of 1991 that America's strategic eyes were actively integrated into every phase of theater warfare.⁴² This integration was and is necessary for the modern battlefield commander to monitor today's expanded theater of operations. Just as telescopes once provided extended vision to the horse-mounted commander, reconnaissance satellites help modern commanders control, manage, and

coordinate simultaneous operations over thousands of square miles. Because of the immense complexities of modern warfare, the orbiting remote sensing systems provide critical information that helps the commander achieve success. Aware of these modern warfare demands, it is now easy to see that in the fall of 1990, America's most secretive strategic intelligence program unknowingly sat on the doorstep of radical change.

We Have No Maps!

When the Coalition forces deployed to the Persian Gulf region, the maps of Kuwait, Iraq, and Saudi Arabia were old and out-of-date.⁴³ To correct this deficiency, multi-spectral imagery satellite systems were used to prepare precise maps of the Gulf area. Multi-spectral images were used to show features of the earth that exceed human visual detection. With the ability to provide seasonally adjusted battlefield maps, the multi-spectral imagery analysis identified land cover, healthy and stressed vegetation, soil boundaries, soil moisture content, fording locations, and potential landing or drop zones. These images also allowed analysts to identify shallow water areas near the coastline and earth surface areas in which spectral changes had occurred. With this information, support personnel and trigger-pullers gleaned data that would help achieve military victory. Desert Shield and Desert Storm engineers had valuable data that enabled plans for military airfield construction; Marines knew which areas were best for amphibious assault; land forces could monitor enemy operations; and air attackers could examine attack routes, verify target coordinates, and identify potential landing zones.

One of the great values of Desert Storm's multi-spectral imagery was its use for aerial combat mission planning and operations. It was combined with other Defense Mapping Agency databases and used by pilots to display attack routes and targets as they

should appear at flight and attack altitudes. Prior to the air campaign, the military electronically overlaid SPOT images of Iraq on digital terrain maps for mission rehearsals. Additionally, these images were displayed in the Mission Support Systems (MSS) vans deployed in the theater. The MSS heralded the first in-theater use of mobile downlink stations.⁴⁴ These units permitted processing and analysis of data by battlefield intelligence units. For combat operations, imagery was a standard part of target folders and air crews expected its uninterrupted availability. When reviewing their tasking orders, they wanted and expected to see a picture of every target.⁴⁵

Examples of the use of SPOT imagery in the air campaign include both destructive and constructive applications. The imagery was a key element in the rapid planning and launch of a successful F-111 attack on a single building in Kuwait City to eliminate several Iraqi general officers.⁴⁶ The SPOT panchromatic imagery closely resembles the resolution and visual appearance of infrared targeting displays.⁴⁷ Thus, the images were very helpful during flight operations. F-117A stealth aircraft pilots carried the imagery from the onset of hostilities. The SPOT pictures helped them attack targets such as the Iraqi air defense operations center, Ministry of Defense, Intelligence Center, and other high priority targets.⁴⁸ To assist in the *Scud* hunts, SPOT imagery was used to identify terrain or man-made features where Iraqi missile launchers might hide.⁴⁹

Equally important, the SPOT imagery helped avoid the loss of civilian lives by identifying the locations of mosques, hospitals, schools, and residential areas. Attack angles for specific weapons were calculated so that bombs or missiles that might impact long or short had the least chance of causing collateral damage.⁵⁰ On at least one occasion, SPOT imagery assisted in the rescue of a downed F-16 pilot.⁵¹ Rescue mission

planners used the images to examine the topography of the area where the pilot ejected. They made judgments about where he would be likely to go based on seeing the same topography from ground level. During the rescue operation, the imagery was used to guide forces to the area.

With its low resolution quality, SPOT's main contributions came from its ability to provide bathymetric, hydrographic, and terrain categorization in support of air, naval, and ground combat operations. In short, this exceptional view of the territory and composition of the land and waterways gave Coalition forces an unprecedented insight into the environment within which they fought.⁵²

The Soviets Views

The Soviets were very impressed by America's space abilities in theater warfare.⁵³ As a provider of much of Iraq's war equipment, they were dismayed that space-based reconnaissance systems detected and smart weapons quickly destroyed much of the Iraqis' modern equipment. Despite the Coalition's success in this area, the Soviets were pleased with the Iraqi *maskirovka*⁵⁴ techniques. The effectiveness of Iraqi camouflage techniques drew positive remarks from several Soviet officers.⁵⁵ The late Marshal Sergei Akhromeyev commented that Iraqi systems of decoy targets and decoy target groupings caused problems for Coalition forces in the first weeks of the air war. General Maltsev speculated that up to 50 percent of the first Coalition strikes were carried out on false targets because of Iraq's extensive deployment of sophisticated dummy air defense systems.⁵⁶ Of even greater significance, Iraq was able to use basic camouflage and dispersal techniques to conceal ballistic missiles, chemical and nuclear weapons related equipment, and probably other information as well.⁵⁷

The Uniqueness of the Gulf War

As a commercial resource, SPOT's value in theater warfare has led many to speculate on the threat posed by a future adversary's acquisition of high quality imagery. One of the unique features of the Gulf War was the broad Allied Coalition that included the majority of space-based reconnaissance-capable nations. Although Iraq had procured SPOT imagery prior to its invasion of Kuwait, the French terminated all sales of Gulf-related imagery within days of the invasion.⁵⁸ Being a commercial venture, the board of directors stated their intent to sustain a non-military image. A spokesperson for the corporation stated that the board of directors did not want SPOT to appear to the general public as a company that aggressively follows military developments.⁵⁹

The official's statements do not indicate a categorical refusal to allow SPOT to provide imagery during conflict or war situations. SPOT officials have repeatedly reminded the world of the corporation's open access policy and refusal to censor its imagery products.⁶⁰ Rather, it was the unique circumstances surrounding the Gulf War that caused the French corporation to temporarily modify its policy. When it has viewed a conflict situation as an opportunity to provide newsworthy imagery, it has readily offered to do so.⁶¹ It was thus the unique high level of belligerence and subsequent world condemnation of Iraq's invasion that led SPOT officials to refuse to supply imagery and to publicly state that it is not their role to track military forces.⁶² Interestingly, their altruism in this situation would have quickly disintegrated if any other imagery agency had decided to provide similar data.⁶³ At the time, the only other agency that could have made such a decision was the Earth Observation Satellite Company that operates LANDSAT. According to Phillipe Renault, Deputy Director-General of SPOT Image, if EOS had sold

LANDSAT images to Iraq, SPOT Image would have done likewise in the interest of business competition.⁶⁴

As the world approaches the twenty-first century, international economic competition is preparing it for unprecedented access to high quality imagery data. Thirty years of technological evolution and international competition have significantly altered strategic space intelligence. Its employment has changed and its ownership expanded. Imagery intelligence has emerged from its highly secretive cocoon; it has experienced an enormous technological revolution; and most recently, its value has been applied to the operational and tactical levels of warfare. Having reached the end of this short review of the emergence, development, and transformation of strategic space intelligence and the military space community, this monograph will now look to the future. The first task for Part II will be to provide a perspective on modern warfare; to provide the context in which imagery intelligence data will be used.

PART TWO: THE FUTURE

The Forms of Modern Warfare

Before attempting to speculate on a future adversary's use of imagery intelligence data in warfare, it is important to gain a perspective on the context in which it may be used, that is, the strategist needs an understanding of some of the variations of modern warfare. This is critical because strategists must recognize that not all adversaries are the same, nor are many at an evolutionary position similar to that of the United States. Each of the potential adversaries the United States may face occupies its own unique region of a multi-dimensional warfare evolutionary scale. Each adversary's technological, organizational, and conceptual capabilities will widely vary. Thus, they cannot be engaged in like manner. A singular employment strategy will not work against diverse adversaries and should not be blindly pursued. The discussion that follows is a departure from traditional warfare analysis. It is offered as another perspective from which to look at the evolution and complexities of modern warfare.

Understanding Warfare

Modern warfare is a multi-faceted enterprise, one whose evolutionary complexity has mirrored that of human society. This complexity ensures that humanity's attempts to explain modern warfare are as taxing today as they were for primitive humankind.⁶⁵ While primitive humankind grappled with the rudimentary skills that characterized early warfare, humanity must attempt to put its arms around many forms of warfare that include highly technical tools and complex organizational and doctrinal concepts. While no individual

can master all of the complexities of modern warfare, those complexities can be described by manageable concepts and frameworks.

Warfare is the human expression of the battle for ascendancy. At its roots lay differences about the desirability of the status quo. Status quo issues may concern territory, power, legitimacy, dominance, ideology, or a host of other topics. Each entity or actor on the international or national landscape has a variety of tools and methods for preserving or attempting to change the status quo. The international battle for ascendancy remains the purview of a small subset of humanity until one side determines that a core interest, value, or belief is threatened or perhaps that the status quo power is incapable of representing the interests of a subset. While a state of war may be referred to metaphorically very early on (for example, a trade war), the military is accustomed to referring to the existence of a state of war only when it is directed to and becomes engaged in force application against the tools of an opposing force. Once a military force is engaged, there are three possible outcomes: the status quo is changed, the forces languish in stalemate, or there is no change to the status quo. If the group seeking change is victorious, it becomes the guardian of the contemporary status quo. The defeated force then becomes the entity seeking to change the status quo at a later point in time. A diagrammatic interpretation of this concept is offered in Figure 2.

The Forms of Modern Warfare

In trying to gain a perspective on this 'visible' portion of the warfare spectrum, it becomes apparent that throughout their evolution, people have improved their warfighting skills by unlocking technological and cognitive secrets. Using technological advancements as a categorical base, humankind has developed three definable forms of warfare. This

categorization is organized by the concept that certain technological advancements have produced significant evolutionary fractures. The fractures have signaled a major change in size of the adversarial group that an entity is able to coerce. The three forms of warfare are primordial, industrialized, and nuclear warfare. Figure 3 provides an overview of two dimensions of this multi-dimensional framework.⁶⁶

As humanity develops each new form of warfare, it continues to maintain and refine its earlier forms. As the secrets within each form are unlocked, humanity modifies the range of its technical coercive capability. Additionally, each new technical ability challenges humanity to harness that new power, focus it, and exploit it through higher orders of organizational and conceptual abstraction. In some cases, for example, Napoleonic warfare, the warriors' lethality was increased through organizational improvements. In other cases, for example, nuclear warfare, the owners have attempted to harness the latest destructive tool to make it more useable. The technological, organizational, and conceptual achievements are pursued in the belief that they will elude the adversary and thus provide success in warfare. Without attempting to delve too deeply into the three forms of warfare or reach into other aspects of this multi-dimensional analysis, a superficial examination is in order.

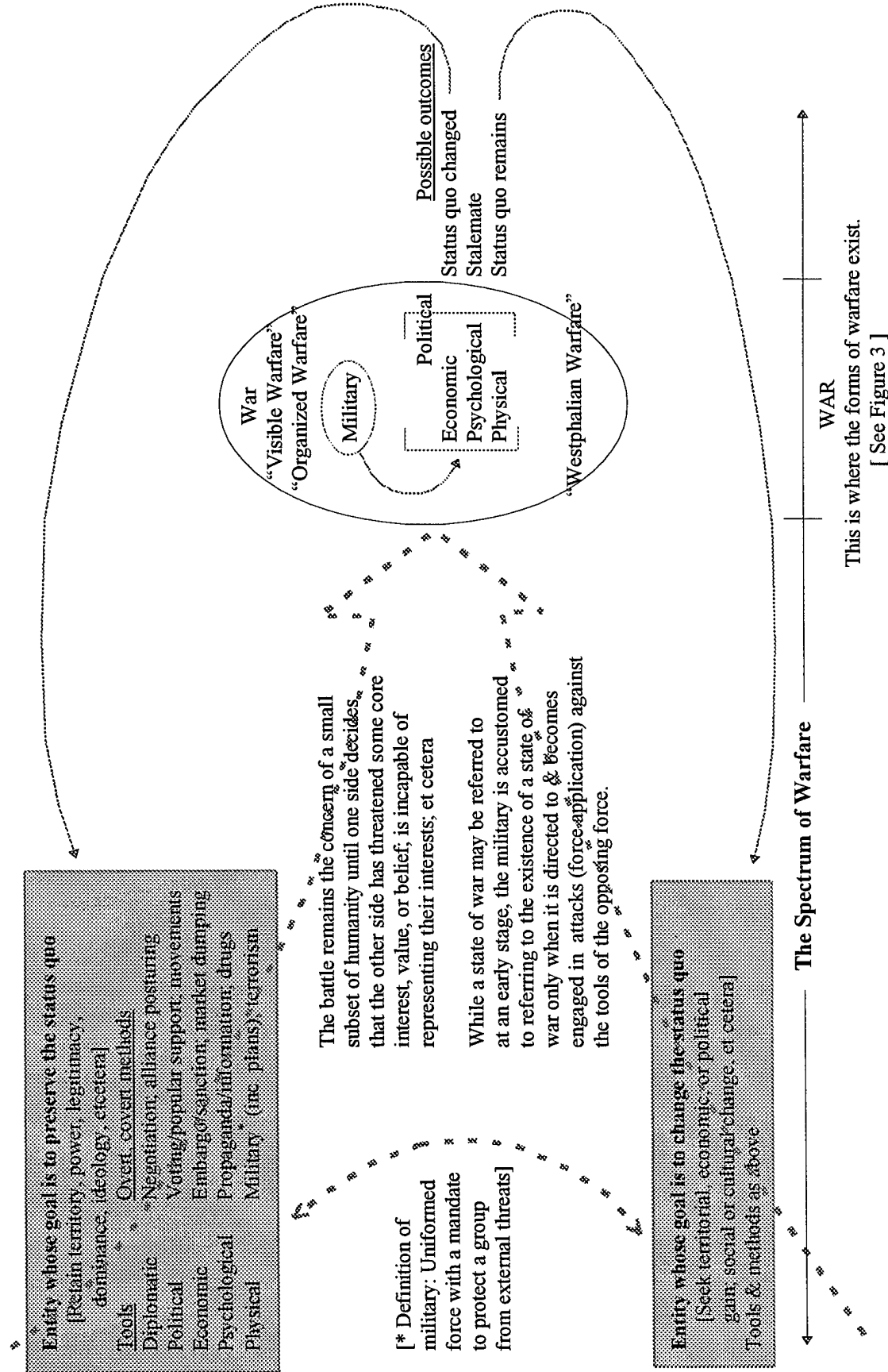


Figure 2: Warfare—The Human Expression of the Battle for Ascendancy

<p>Note</p> <p>Words printed in regular font represent technological advancements Words printed in italics represent organizational / conceptual advancements</p>		?	Future ?
		SPACE WARFARE	
		Miniature nuclear bombs	
		Tactical nuclear bombs	
		Strategic nuclear bombs	
		NUCLEAR WARFARE:	
		Foundation: Coerce larger group / population	
		Evolution: Reduce destructive power, increase usability	
		Missiles	
		Computers	
		Tactical space assets (GPS, DMSP, COMM)	
		Airplanes	
		Radar	
		Deep Battle	
		Maneuver Warfare	
		AirLand Battle	
		Air campaign	
		Tanks	
		Chemical / biological agents	
		Machine guns	
		INDUSTRIALIZED WARFARE:	
		Foundation: Coerce large group (e.g., military)	
		Evolution: Precision lethality	
		Guns / rifles	
		Swords	
		Tribal warriors	
		Clubs	
		Hand-to-hand combat	
		Martial Arts	
		Psychological warfare	
		PRIMORDIAL WARFARE:	
		Foundation: Coerce individuals / small groups	
		Evolution: Large mass of organized warriors engaged in one-on-one combat action	
		Non-lethal weapons	
		Protracted guerrilla warfare	
		Chemical / Biological	
		Genetic Terrorism	
		DCX	
		Power	
		UAVs	
		TAVs	
		Nuclear terrorism	
		ANARCHY?	
		SPACE WARFARE	
		ANARCHY?	
		Genetic Terrorism	
		ANARCHY?	

Figure 3: The Forms of Modern Warfare
(Categorized by Mankind's Development of Group Lethality Tools)

The foundation of primordial warfare is based on an entity's need to coerce individuals or small groups. This form includes hand-to-hand combat and the use of elementary weapons such as clubs, swords, and small firearms. Organizationally, its evolution has been expressed through Napoleonic, tribal, and protracted guerrilla warfare. Recent technological developments in this form of warfare seek coercion through the use of non-lethal weapons.

Industrialized warfare is the form of warfare that members of militaries prefer to deal with because it typically concerns forces that resemble themselves and which operate in what is commonly referred to as conventional warfare. The foundation of industrialized warfare is based on an entity's need to coerce a larger organized force. It includes all of the non-nuclear tools that industrialized society has created for use in warfare. Examples of such tools include the machine gun, tanks, airplanes, missiles, many of the space assets, and information technologies. The many entities who have gained industrialized warfare capabilities provide extensive variety to this form of warfare. Each has mastered its own unique level of technological, organizational, and conceptual sophistication. Additionally, in this form of warfare, humanity has succeeded in organizing systems of tools into complex and coordinated attack systems. For example, this form includes Germany's concept of blitzkrieg, the United States Army's AirLand Battle doctrine, air campaigns, and emerging concepts of information warfare. It is in this form of warfare that humanity now spends most of its physical, organizational, and conceptual resources in both vertical (advanced technology) and horizontal (advanced organizational and conceptual) development.

The foundation of nuclear warfare is based on an entity's need to coerce a very large group or entire population. In this form of warfare, use of its weapons can quickly transform the objective from coercion to annihilation. This form of warfare so preoccupied politicians and strategists during the Cold War that its definitional and organizational complexity quickly overshadowed that of preceding forms of warfare despite its shorter history. Strategic thinkers wrote volumes about deterrence; superpower nations devoted enormous treasures to placing photo-reconnaissance and infrared satellites on orbit to locate nuclear weapons and to alert its citizens of their employment. Current developments in this form of warfare may prove to be very difficult to deal with in the near future. Recent efforts in this form of warfare have concentrated on ways to make nuclear weapons less destructive and thus more useful. There are frequent reports that uranium is trickling out of the former Soviet Union. Worse yet, 'red mercury', potentially the key ingredient of miniature nuclear bombs, may actually exist despite the skepticism of some experts.⁶⁸

These three forms of warfare encapsulate modern warfare. Probably the single most important fact to keep in mind is that all of these warfare forms exist in today's world. Technical, organizational, or conceptual developments within one form of warfare do not negate or supplant the other forms. Humanity merely continues to refine each form to fully exploit the advantages within each. Additionally, an entity may combine portions of the forms of warfare or elements within the forms to coerce an adversary. As an example, during the Vietnam war, the North Vietnamese combined portions of industrialized and primordial warfare. Being able to extract from the warfare forms those elements that best fit an entity's capabilities and resources provides a great deal of

flexibility when seeking to coerce adversaries. Today's modern warfare reservoir offers great variety and complexity depending upon the limitations of the political objectives, the physical, organizational, and conceptual capabilities of the actors and their financial resources.

Looking into a crystal ball, the future warfare bazaar may reveal the transition of current technological breakthroughs as creators of new fractures that enable different forms of coercion. This in turn would modify the framework to include additional forms of warfare. One possibility is that an actor will choose to depart from international agreements and deploy space weapons that are capable of holding the entire planet hostage. This would definitely cause an evolutionary fracture, adding space warfare as a new form. Another possibility is that the proliferation of emerging chemical, biological, nuclear, or genetic terrorism weapons will reveal themselves as similar transitional devices. They could become originators of humankind's transition from today's state ordered system to one dominated by anarchy. On this note, this study turns to look at imagery's role in modern warfare.

Imagery in Future Warfare

Keeping in mind the three forms of warfare, the multitude of variations within each form, the fact that coercers may combine elements of each form, and the immense diversity of capabilities that have been achieved by potential adversaries, how important will imagery be in future warfare? Furthermore, how will the United States respond to an adversary's acquisition of indigenous or commercial space reconnaissance products? These questions provide the focus for the remainder of this project.

Because modern warfare comes in so many variations, the United States must be able to analyze an opponent's physical, organizational, and conceptual capabilities. Among the assets the United States will use to unravel these capabilities are its well-established satellite imagery assets. National and international actors who appreciate imagery's value and see the ease with which it may be acquired will seek to exploit it. With its recent Desert Storm experience and continued technological superiority, the United States military will continue to lead this evolution.

Imagery's Role in Modern Warfare

Imagery's primary value will remain at the strategic level of warfare because of its continuing importance with respect to combating nuclear warfare. In a world where nuclear proliferation is a growing concern, reconnaissance satellites' ability to peer into restricted areas will continue to prove that strategic space intelligence is necessary for maintaining peace in a nuclear world.

Imagery's value in industrialized warfare will vary depending upon the adversary's capabilities. For America, reconnaissance satellites comprise a portion of the system of systems it uses to gain strategic, as well as its new-found operational and tactical, intelligence during warfare.⁶⁹ This highly evolved system of systems includes satellites, manned and unmanned aircraft, and surface forces. Potential adversaries' capabilities are less evolved, but could include some combination of these forces being used at all three levels of warfare. The technologically sophisticated actors will have indigenous imagery capabilities and healthy imagery databases; other actors will have purchased imagery and may have similarly healthy databases; some will not have any imagery capability. A few will have achieved capabilities comparable to those of the United States. These nations

may own indigenous capabilities or have purchased strategic imagery and be capable of augmenting it with operational and tactical unmanned aerial vehicles.⁷⁰ Other adversaries will be at less evolved stages of development, perhaps able to employ imagery only for general information.

As expected from many industrialized warfare tools, satellite imagery intelligence offers less in primordial warfare than in the other forms. In this form of warfare, it may provide only general strategic intelligence information. More useful media for imagery intelligence in this form of war are airborne strategic and tactical reconnaissance platforms, in particular, unmanned aerial vehicles.

If not critical in the conduct of primordial warfare, imagery intelligence will continue to be one of the most important military uses of satellites in industrialized and nuclear warfare. Its denial to an adversary in those forms of warfare could prove critical for the United States. Thus, the following two sections will provide information essential for understanding the scope of the challenge facing the United States.

Understanding the Challenge

Satellite imagery is no longer the preserve of major powers and specialized units with top secret clearances. Japan, China, India, and Israel have all launched and placed on orbit imaging satellites with varying capabilities. Brazil, Canada, and Great Britain have plans to develop imagery systems. Twenty meter resolution multi-spectral and 10 meter resolution panchromatic imagery is commercially available from SPOT Image Corporation; five meter resolution panchromatic imagery is available from Russia's Soyuzkarta agency. By the year 2000, several corporations will provide imagery of one meter resolution quality.

SPOT Image corporation's commercial network extends beyond that of any other supplier and continues to grow.⁷¹ The military value of SPOT imagery during the Gulf War is resulting in millions of dollars in procurements from international military users.⁷² As of 1994, SPOT Image Corporation was operating ground receiving stations in 14 countries and selling imagery products on an unrestricted basis.⁷³ In addition to its current capabilities, SPOT Image plans to upgrade its network by launching SPOT-5 in the year 2000. SPOT-5 will provide five meter resolution quality data.⁷⁴

Having surprised the world in 1987 when its Soyuzkarta agency announced its intention to begin selling high quality imagery of the Soviet Union, Russia continues to offer strong competition in the satellite imagery business. As of today, Russia's KFA-100 cameras provide the best commercially available imagery data.⁷⁵ Although the KFA-100's imagery is advertised as being of five meter resolution quality, customers have received imagery assessed at 1.3 meters resolution.⁷⁶

For many years, the United States refused to launch commercial satellites whose resolution was better than 10 meters;⁷⁷ however, with the combined pressures imposed by the Soyuzkarta sales and the lack of restrictions on non-United States commercial space agencies, it was clear to the United States government that the superpower monopoly on high quality satellite imagery was ending. As a result, early in 1987, the United States announced that it had lifted its 10 meter resolution launch limit.⁷⁸ By the end of this year, a commercial United States corporation will provide three meter resolution imagery. In 1997 and 1999, two American firms plan to begin offering one meter resolution quality data. Table 1 provides a summary of the types of imagery data that will be available in the next few years.⁷⁹

Table 1: Planned Imagery Systems 1995-2000 ⁸⁰

1995	USA	World View	3m				
	Russia	Almaz-1B (radar)	5m	1996	Japan	ADEOS 1 & 2	8m
	Canada	Radarsat (radar)	10m	1997	USA	Eyeglass	1m
	India	IRS-1C	10m	1999	USA	Space Imaging Inc.	1m
	France	SPOT-4	10m	2000	France	SPOT-5	5m

With these developments in the remote sensing world, it is likely that future adversaries will own or have access to high quality imagery data. Iraq's limited access along with SPOT Image Corporation's willingness to restrict its data minimized the risk of exposure of American combat deployments, movements, and battle plans in 1990 and 1991. Additionally, Iraq could not begin to cope with the extent of the Coalition's satellite and airborne reconnaissance capabilities. In the Gulf War, these, along with America's other overwhelming capabilities, were the exclusive province of Coalition forces.⁸¹ However, with the numerous sources discussed above, the Gulf War may be the last in which America holds an overwhelming imagery advantage. It appears certain that in future warfare, the enemy will have our eyes. But what exactly do these eyes give to an adversary?

Militarily Useful Imagery Data

For surveillance data to be useful for military purposes, its resolution quality needs to be 25 meters or better.⁸² With 25 meter resolution, an analyst can identify such things as large buildings, road structures, rivers, and lakes. According to Major General William K. James, director of the Defense Mapping Agency in 1991, effective military mapping requires a system with three to five meter ground resolution, five-band spectral resolution, precise metric data, stereoscopic coverage, and broad area collection.⁸³ This kind of imagery provides the ability to identify, for example, bombers on an airstrip, ingress and

egress routes; differentiate between soil types and elevation; and, if provided in digital format, a medium that allows pilots and soldiers access to a volatile display system capable of providing battlefield familiarization.

For terrain analysis or general detection capabilities, low resolution imagery systems work well. For precise equipment identification, the best system is that which provides the highest resolution. If one is viewing, for example, a TU-95 *Bear* bomber that is 49.5 meters long and has a wing span of 51.2 meters, the aircraft can be detected using the 10 meter resolution provided by SPOT panchromatic imagery. General identification can be attained using the five meter resolution imagery provided by the Soyuzkarta agency. To begin to see, for example, engine details, the analyst needs the more precise imagery that will be commercially available before the year 2000. If one is viewing a much smaller object, for example, a MiG-29 *Fulcrum* fighter aircraft, the minimum resolution required for detection is 4.6 meters. For general identification, one needs 1.5 meter resolution. For precise identity, one needs 0.9 meter resolution. For description, one needs 0.15 meter resolution. Table 2 provides a synopsis of the value of imagery of various qualities.

Looking to the future, America's military must assume that its most technologically advanced adversaries will seek to achieve a level of proficiency similar to or better than that achieved by the United States in Desert Storm. As her adversaries seek this, the United States military continues to analyze its Gulf War successes and failures in the never ending quest to ensure that America's forces are the most capable in the world. Because of the lessons of this war, significant changes are underway in the United States military.

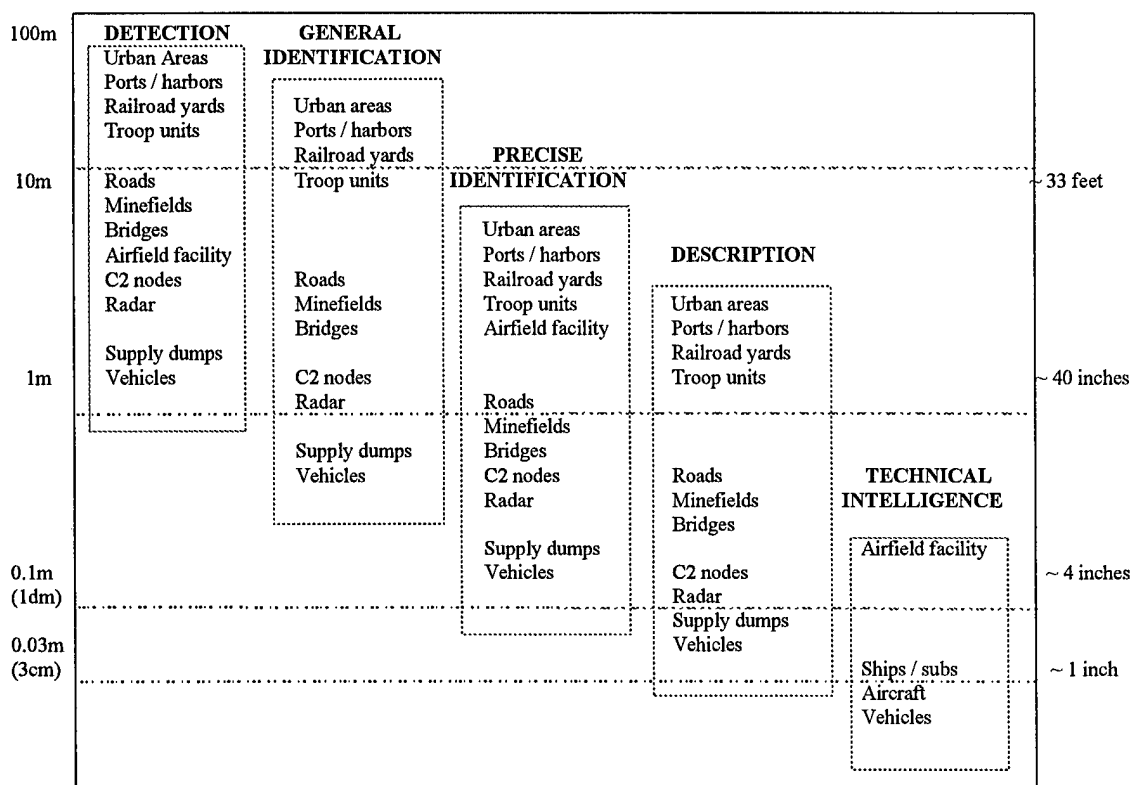
The Leading Edge

America's unparalleled experience in the reconnaissance satellite world and her recent Desert Storm experience affords her a position at the leading edge of imagery exploitation. She has quickly moved to internalize some of the Desert Storm lessons and prepare for future warfare. Two exciting developments in this area are the DIGITAL WARRIOR and EAGLE VISION programs.

DIGITAL WARRIOR allows United States combat units to merge intelligence data and computerized mission planning. Using this capability, units can load their mission programs into simulators to practice upcoming missions or into weapons computers to carry out attacks.⁸⁴ The DIGITAL WARRIOR system that enables this uses commercially available desktop personal computers to bring together intelligence data, weapons specifications, and information updates as the mission unfolds.⁸⁵

Both the Air Force and Navy⁸⁶ recommended that SPOT imagery become an integral part of a much more operationally oriented space-based imaging reconnaissance capability.⁸⁷ The Air Force's EAGLE VISION program will allow small mobile ground stations to receive SPOT imagery directly from spacecraft.⁸⁸ In many instances, the United States military has found that the broad fields of view provided by SPOT imagery were much more useful and available than the narrow fields of view provided by advanced national spacecraft. According to Air Force planners, if the air crews had been limited to using standard maps, they had approximately a 30 percent chance of destroying a target. Using SPOT data, the first strike success rate jumped to 70 percent.⁸⁹

Table 2: Resolution Required for Specific Military Tasks⁹⁰



(vertical scale on the left lists resolution using the metric scale; on the right vertical scale, the resolution is listed using the English scale)

The significance of these changes is that the Gulf War marked a turning point for the American military's use of space-derived imagery data. The Gulf War proved that the strategic systems developed during the Cold War had operational and tactical value.⁹¹ The on-going acquisition of imagery satellites and their products by potential adversaries alters the future warfare equation and thus raises the priority of the space control mission. Part III will discuss the space control mission in the context of employment against imagery systems and analyze a commercial surveillance system to determine how best to deny such information to a future adversary.

PART THREE: MEETING THE CHALLENGE

Denial

With the preceding knowledge of imagery's history as well as a different perspective on modern warfare and imagery's potential role, the stage is set for the final section of this study. This work now moves forward to meet the challenge of space control in a multi-polar, technologically advanced world. For the space strategist, this means understanding the space control mission and having the ability to work through the problem of effective post-Cold War, post-Gulf War space control measures. To be effective, the strategist needs an awareness of the effects of targeting various portions of the space systems infrastructure. With the international stampede to acquire imagery data, reconnaissance satellites may represent one of the first categories of space systems against which the United States may need to exercise active space control measures.

The Space Control Mission

Space control is an amorphous term whose current definition has lost its connection with United States Air Force doctrine. According to Air Force Manual 1-1, control has two sides: it permits friendly forces to operate more effectively and it denies these advantages to the enemy.⁹² Joint Publication 3-14 defines space control as combat against enemy forces in space and their infrastructure.⁹³ This narrow definition lacks the substance and flexibility of the Air Force's use of the term control and thus may close a strategist's mind to the broad spectrum through which American instruments of power may successfully deny the use of space assets.

A more encompassing definition of space control should acknowledge both sides of the term. It could describe the denial portion of the term as the diversion, delay, disruption, or destruction of an adversary's space capability. The dual objectives of access and denial require a variety of capabilities, ranging from protective measures for friendly satellite systems to destruction of an adversary's spacecraft. Both lethal and non-lethal means can be employed to limit or deny an adversary's capability to use space systems or to distort the information they provide.

Space-derived intelligence data provide early indications and warnings of crises; ensure dissemination of targeting and planning data; remove uncertainties about the weather and the location and synchronization of forces; and facilitate effective command and control of forces. They help national leaders exercise the political, economic, and diplomatic instruments of national power. It is the access to these capabilities that United States forces may be directed to deny through effective space control actions.

To deny the adversary's use of space, United States forces may target a wide range of assets including, but not limited to: orbiting spacecraft, launch sites, production facilities, research and development laboratories, operations headquarters, fixed and mobile command and control ground sites, data reception and analysis sites, power generation facilities, data links, and the many technicians, operators, analysts, and management personnel who create and operate these highly technical systems.

The spectrum of denial ranges from achieving temporary or limited data loss to causing extensive long-term systemic loss. Some examples of denial actions include but are not limited to: implementing an international agreement to shut off a satellite's downlink, terminating imagery sales, destroying ground sites, destroying or disrupting

system software programs, spoofing or jamming link signals, damaging or disrupting satellite subsystems, and disabling or destroying the satellite. Before choosing any of these measures, the strategist must determine the outcome being sought and what tools can be employed to achieve the intended effect while concurrently minimizing unintended effects.

Before proceeding with the denial analysis, a short discussion of political constraints is in order. Current international law curbs direct attacks against satellites. Because satellites are the sovereign territory of the satellite owner, attacks against them are considered violations of national sovereignty.⁹⁴ In spite of this fact, most of the literature on space control is monocular in its discussion of the means of space control. Few have emerged from the trappings of Cold War concepts to see space control as anything beyond employment of anti-satellite weapons.⁹⁵ That topic has kept the military space community and many national level strategists in its grip since the dawn of the space age and hindered analytical thought about how to deny access to space's bounty.

Furthermore, armed forces' personnel at the tip of the warfare spear spend most of their time focusing on the weapons of war. For those at the leading edge of technology, it is easy to understand this focus. The weapons are high technology 'toys' that fascinate the imagination. This preoccupation is inadequate for the strategist. The strategist must move beyond this fascination and focus on the outcome that is being sought when the United States uses its military or other instruments of power.

Denying the Advantages

During the Cold War, the United States military's adversarial problems were in clear focus. There was a much better understanding of who the enemy was and what

capabilities he would bring to a conflict. The problem is much more complex today and for future warfighters. Considering only the space control portion of the conflict equation, during the Cold War, America faced an adversary who owned highly capable reconnaissance satellites and existed in a closed society within a large landmass. With the limited technologies of the day, ASAT attack was perhaps the only viable method of space control. Today, the landscape is much different. Tomorrow's adversary may be receiving imagery data from foreign or domestic commercial vendors. United States governmental agencies may be receiving data from some of those very same sources or include their use in contingency plans. This concurrently complicates yet broadens the scope of the denial portion of space control's mission. Now, more than ever before, denial efforts cannot be executed without considering the political, economic, and physical ramifications of those efforts.

The strategist must determine what effect is needed and how best to achieve that effect. Looking at the problem of satellite imagery control, as mentioned earlier, the range of objectives extends from temporary or limited data loss to the long term future loss of related space systems. For each of these, there are numerous ways to achieve the objective depending upon the circumstances surrounding the actors, the linkages between the actors and those unrelated to the conflict situation, the conflict situation itself, the space systems, the actors' capabilities, and so on. Many such factors will impact the national strategy. Table 3 was developed as an aid for developing space strategy. It does not purport to represent all possible effects, weapons, or means. Rather, it is offered as a tool for the space strategist who is attempting to approach strategy through rational analysis.

As shown in Table 3, the strategist will achieve effects for varying lengths of time. The effect may be felt by an isolated group of users or by all agencies who depend upon a launch site to gain access to space. During the heat of battle, one common goal is immediacy. This is especially true for the United States, where there is a desire to terminate conflicts quickly. For an on-orbit, operational space system, this raises the importance of the first group of options and lowers the importance of attacking, for example, the spacecraft's headquarters facilities, fabrication facilities, and launch sites.

To gain an immediate effect on the adversary while avoiding costly and unintended effects against friendly users, the strategist must look to the measures shown at the top of Table 3. Of those means, some are much easier to implement than others. For example, while an exacting software virus or worm could be employed to achieve temporal and specific results, the warfighter must have had or gain access to the system to employ this tool. This may require access long before the current adversary was considered to be a potential threat. Most space systems employ highly secure cryptology devices to avoid such problems. Thus, while listed as an option, this weapon may not be feasible.

Table 3: Some Means of Denial

Objective	Tool or Weapon	Means of Denial
Immediate temporary or limited data loss	Diplomacy / ownership	Agreement to terminate downlink
		Shutter control ⁹⁶
		Terminate imagery sales
	Physical attack	Attack a ground C2 or receiver site that has a backup system
	Software virus / worm	Destroy software coding to temporarily disrupt spacecraft or site operations
	Electronic warfare	Spoof or jam signal links to disrupt or degrade spacecraft or site operations
Immediate long term data loss	Directed energy	Temporarily disrupt or degrade spacecraft operations
	Physical attack	Attack ground receiver station that does not have any backup system
Immediate satellite destruction	Directed energy	Cause repairable damage to spacecraft
	Physical attack	Destroy all ground C2 sites to cause spacecraft malfunction / destruction
	Electronic warfare	Spoof / jam C2 links to cause spacecraft failure
	Directed energy	Cause irreparable damage to spacecraft
Potential future or long term impact	Physical attack	Kinetic kill
		Use ASAT to destroy spacecraft
		Headquarters
		Remove replacement capability by destroying spacecraft storage or fabrication facilities
		Remove replacement capability by destroying launch site

Looking at another of the options in this category, a physical attack against a receiver site that is known to have a backup system may provide the temporal success needed. It may remove the space assets from the adversary's tool box without causing significant long term effects. It may also maintain the flexibility for more inclusive measures at a later time.

Switching to the middle categories, directly attacking the satellite will have immediate effects, but it also has many unattractive consequences. First of all, in today's interdependent information-based society, destruction of a satellite may effect more actors than desired. It may effect a very large group of users, some of whom may be allies or even the United States government. For those with orbital analysis or astronomical experience, the idea of shattering large on-orbit satellites immediately brings to mind two nightmares. The first is the orbital analysts' nightmare of trying to identify and track (perhaps for hundreds of years) the hundreds of resultant debris objects. The second is the orbital analysts' and astronauts' nightmare of determining and reacting to the destructive effects that those pieces of debris may have on friendly satellites or manned spacecraft.⁹⁷ Additionally, such an attack minimizes the coercive leverage gained by less destructive measures. Because of the far reaching unintended effects caused by spacecraft destruction, it is one of the least preferred of the attack options. Permanent or temporary disablement through other means, for example, electronic warfare, may achieve the desired effect without risk to American or allied manned or unmanned spacecraft.

Looking briefly at the final category, when dealing with an on-orbit system, these targets appear to be the least beneficial of the targeting categories. It is possible that none of them will have an immediate effect upon the conflict.⁹⁸ For example, attacking a

spacecraft's headquarters will not immediately stop the data flow from the satellite to the command and control or receiver stations. At best, such an attack will have an unknown future effect on operations due to the loss of financial and management support. Similarly, attacking the launch facility, or spaceport, may deny the adversary's ability to launch replacement satellites, but it may also remove that spaceport from the small inventory of available launch facilities and cause far-reaching long-term effects on the entire space industry.⁹⁹

In concluding this overview of selected denial measures, one final item is important to keep in mind. When considering the options, the decision-maker must remember that many commanders are involved in all phases of conflict and that they may require different measures to achieve their campaign objectives. Without close coordination, one commander may demand the elimination of a satellite or ground station while another needs to keep that same system operating to permit deception operations. This is where the demands of warfare and the global nature of satellite systems require that a space denial campaign be centralized in the hands of a space systems expert.¹⁰⁰

The space control mission is becoming increasingly important as the world's powers become proficient in exploiting space resources. Regardless of who becomes an adversary of the United States, the military must be prepared to advise its decision-makers about the most effective means for achieving space control. The complex and interconnected contemporary world demands that this advice be given only after completing an analysis similar to that offered above. Simply advocating, for example, spacecraft destruction will not answer the question of how to achieve space control. In what follows, the results of the above analysis will be applied to the world's leading

commercial imagery provider to illuminate the implications of attempting to deny its data to a future adversary.

An Analysis of the SPOT System¹⁰¹

While the SPOT system may not be the only means by which to procure high quality imagery intelligence in the near future, it is analyzed here because it has the most extensive network and an aggressive marketing plan to ensure its continued relevance.¹⁰² As with any space system, there are four critical components for SPOT operations: the spacecraft, the ground stations, the communications links, and the personnel. To deny SPOT imagery data to an adversary, some or all of these components may need to be targeted. Exact target selection would need to consider the conflict level, constraints, and the desired outcome.

An Overview of the SPOT System

The main contractor for the SPOT program is the *Centre National d Etudes Spatiales* headquartered in Toulouse, France. CNES is responsible for orbit maintenance, payload programming, and data reception and pre-processing. Upon successful launch from the spaceport at Kourou, French Guiana, the SPOT spacecraft travels in a circular sun-synchronous orbit, designed to provide imaging coverage at approximately 10:30AM local time. Its altitude is 832 kilometers¹⁰³ and its orbital inclination is 98.7 degrees.

The SPOT spacecraft includes twin high-resolution sensors called high-resolution visible imagers that acquire either panchromatic imagery in the 0.51 to 0.73 micrometer wavelength range or multi-spectral imagery at lower spatial resolution.¹⁰⁴ The high-resolution visible instruments measure the reflected solar energy radiated from the earth's

surface to create an image. The imagers are comprised of a camera (including the optical system), light sensitive detectors, and an electrical subsystem for signal processing and camera control.¹⁰⁵ Recorders on SPOT-1, -2, and -3 can hold 22 minutes of data. With SPOT-4 and SPOT-5, this will increase to 40 minutes of data.

Moving to the ground segment, space systems such as SPOT require extensive data processing facilities. The complete remote sensing system must provide capabilities for command and control of the spacecraft, imaging sensor command and control, telemetry data acquisition, telemetry decommutation¹⁰⁶, extraction of the digital imagery from the telemetry, formatting and display of the imagery, and delivery of data products to the users. Processing operations are categorized into several levels of sophistication.¹⁰⁷ The resultant products are supplied in several formats including standard computer-compatible tapes, MS-DOS diskettes, photographic format, and CD-ROM.

There are two types of fixed data reception stations: Station Reception des Images Spatiales, or SRIS, and SPOT Direct Receiving Stations, or SDRS. The primary receiving stations are the two SRIS located at Aussaguel (SRIS-T), near Toulouse, France, and at Esrange (SRIS-K), near Kiruna, Sweden. These two SRIS receive real-time data as SPOT passes over the north polar region, Europe, and North Africa within 2,500 kilometer range as well as stored images of other regions. Together, these stations' reception capacity is 500,000 images per year. The equivalent of 700 scenes are archived every 24 hour period at each site.

There are 15 SDRS around the world.¹⁰⁸ These stations only receive real-time imagery and are thus limited to the amount of data stored on board the SPOT spacecraft as it comes within range. The locations of the SDRS are listed in Table 4.

Table 4: SPOT Direct Receiving Stations¹⁰⁹

Prince Albert	Canada	Islamabad	Pakistan
Gatineau	Canada	Hyderabad	India
Cotopaxi	Ecuador	Alice Springs	Australia
Cuiaba	Brazil	Lad Krabang	Thailand
Maspalomas	Spain	Pare-Pare	Indonesia
Riyadh	Saudi Arabia	Taipeh	Taiwan
Tel Aviv	Israel	Hatoyama	Japan
Hartebeesthoek	South Africa		

In addition to the SRIS and SDRS fixed data reception sites, the Gulf War coalition forces utilized the first mobile reception systems. Those provided for the conflict were called Mission Support Systems (MSS). Figure 4 provides a summary of the SPOT system network.

Denying the SPOT Imagery Advantage

Denying SPOT imagery data to an adversary may be a challenging task. The strategic level intelligence data it provides can be accumulated over time and kept on file. If the adversary is acquiring timely operational and theater level data, it may be possible to take measures to deny this information.

To cause the immediate temporary or limited loss of data to an adversary, the United States could enlist the services of its diplomatic personnel to convince the French government that SPOT Image should terminate sales or downlink services to the adversary. The precedent for this would be SPOT Image's willingness to terminate sales of Middle East imagery during the Gulf War.¹¹⁰ Air, ground, or sea force attacks could terminate operations at a fixed SDRS or mobile MSS. Human intelligence operatives could be employed to eliminate particular data transfers or to provide misinformation. For

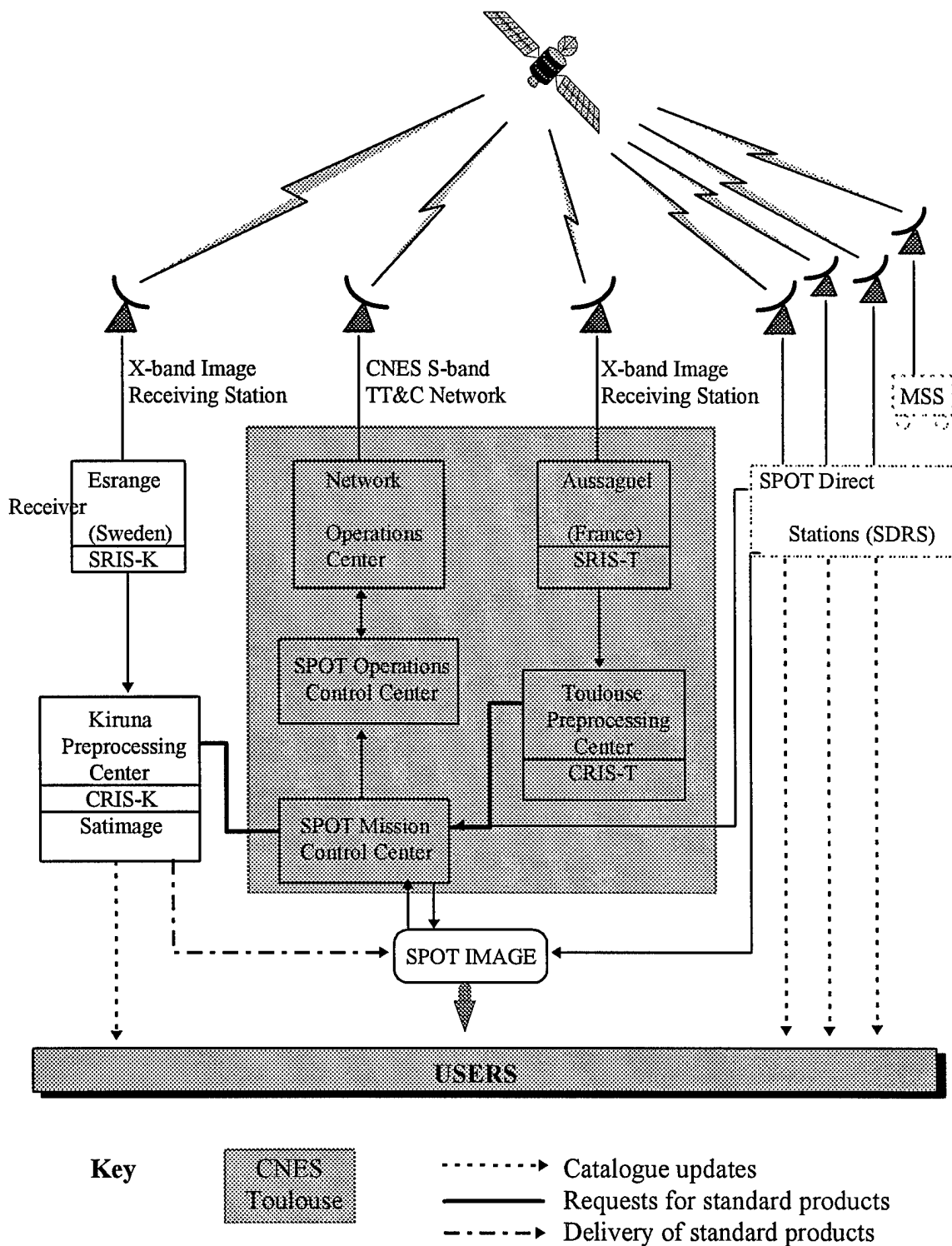


Figure 4: SPOT Control and Data Reception Network¹¹¹

an internationally intertwined system such as SPOT, these may be the only options by which to attempt space control due to the negative side effects of other means.

The options that seem likely to be politically, economically, technically, or operationally unwise or unfeasible include: installing a software virus or worm, spoofing or jamming the spacecraft signal links via electronic warfare or directed energy weapons, attacking the CNES Mission and Operations Control Center and Network Operations Center, the SRIS sites, destroying the SPOT satellite via directed or kinetic energy weapons, attacking CNES headquarters, destroying SPOT fabrication facilities, and destroying the Kourou spaceport. These actions would affect all SPOT customers, cause multi-national discord, disrupt United States military use of the data, obligate the United States government for expensive replacement costs, and if the spaceport is destroyed, cause enormous financial losses across the entire space industry.

Considering the unique problems that this system provides, it is apparent that the SPOT system's international value minimizes the feasible space control actions that can be accomplished by the military. Of the actions discussed, only two, physical attack against a fixed or mobile regional receiver site and HUMINT activities, appear as viable means to gain immediate temporary or limited data loss. Assuming these measures can in fact be successfully conducted, one may achieve very limited results. If the adversary's database is intact, he may still have access to strategic level intelligence and perhaps some operational level data. Perhaps the best that can be expected is the termination of temporal operational or tactical level data.

One final note on the above analysis is essential. The risk of applying the results of a conceptual analysis to a particular system is that one then falsely extrapolates the

attributes of the part (SPOT) to the whole (all space systems). The author has attempted to avoid this error, but also realizes that SPOT represents today's most sophisticated commercial imagery network. It may thus be among the first to cause headaches for American leaders who are tasked with engaging a technologically adroit adversary. An analysis similar to that accomplished above for the SPOT system may yield like results for other satellite systems, in particular, many of the communications satellites. For actors with indigenous systems designed to serve a solitary actor, America would be at greater liberty to take aggressive space control actions. It is thus critical that the strategist have the background information that will clarify the constraints under which the space control measures must operate.

CONCLUSIONS & IMPLICATIONS

In proceeding through this study, the author has attempted to provide information for space strategists and non-space personnel alike. The work has acquainted readers with some strategic space intelligence history, described its revolution, touched upon the significance of using strategic space intelligence in theater warfare, offered a unique outlook on modern warfare, and contributed analytical tools to the space control mission. To place the study in perspective, the conclusions drawn here reach into the future by considering the implications.

America's first space strategists and scientists were determined to provide the tools necessary to ensure security and stability in a nuclear world. Their work provides an example of how human vision can stimulate the achievement of technological breakthroughs that change history. As is so often true, once technological secrets are unlocked and mastered, it is only a short time before the closest competitor closes the gap. Once the digital imagery genie was out of the bottle, it took only one theater war to enlighten the rest of America's competitors about imagery's potential in warfare. For America's military space community, the Gulf War represented a fundamental break with the past. During the Cold War, attempts to demonstrate the operational and tactical value of strategic space assets was seldom encouraged. There was little deviation from the strategic missions and only a few personnel were involved in exploring space systems' value for auxiliary missions. It is thus not surprising that when looking at the military space community's Gulf War shortcomings, critics latch onto the lack of space doctrine for theater warfare. They were destined to find little theater-level doctrine because, quite

simply, the use of America's strategic space assets for theater warfare was not a primary, secondary, or tertiary mission during the thirty years of Cold War military space operations. The only group actively seeking use of strategic space assets in theater warfare were those involved in TENCAP. The space forces used for the Gulf War did not provide everything the trigger-pullers wanted or needed, but they rose to the challenge of turning their world upside down and are credited with significant contributions to the Coalition's success. From this, there are two important reminders for the future. First, obtaining such a fundamental change in focus cannot be executed overnight. Cold War mindsets and procedures still permeate every military space sub-community. Resistance to change will continue until leaders help those communities grasp the requirements of the post-Cold War, post-Gulf War world. Secondly, the strategic space missions have not been replaced by the new operational and tactical ones. Instead, the scope of the latter missions has expanded and their significance been raised. During their enthusiastic exploration of space systems' potentials for theater warfare, space strategists must remember to accept space systems' limitations. Satellite reconnaissance is only one of several methods for procuring timely imagery data. In many cases, the preferred method for acquiring imagery reconnaissance information will still be through the use of airborne strategic or tactical platforms.

As her competitors quickly seek space-derived imagery products, America faces a future where her adversaries may cloak themselves in different forms of warfare. Their unique abilities and combinations of warfare forms and tools must be understood to successfully engage them in combat. Today, a multitude of actors operate spacecraft and do so in consortia. Although America is the world leader in the exploitation of space

reconnaissance systems, her allies and adversaries are closing the gap. They will be skilled at using indigenously produced or commercially procured space imagery. The imagery will assist them in maintaining regional peace as well as in waging war. The responsibility for regional monitoring may become less of an American concern as other nations procure satellite imagery systems and assume monitoring responsibilities. Commercially available imagery data give, at the very minimum, the ability to procure and maintain strategic databases. This allows an adversary to develop attack plans and rehearse missions. The interconnectedness and multiple uses for reconnaissance data suggest that space strategists must analyze the adversary's use of space systems and its international linkages before recommending space control action.

The existence of 'many eyes' makes the space control mission more challenging than at any previous time. It does not, as some proclaim, justify procurement and deployment of anti-satellite weapons or other space weapons for space control. During the Cold War's formative space years, the United States and the Soviet Union could each claim to control space. They owned the space control mission by default: there were no challengers during those early years. Each nation, at various times, owned and demonstrated the anti-satellite weapons by which it intended to exercise space control. But those formative years are now part of the military space community's history. The advent of commercially available space reconnaissance data limits America's ability to control space regardless of the weapons she chooses to develop. If the adversary has developed a strategic database, destruction of portions or all of a space system's infrastructure cannot remove this peacetime endowment. At best, destruction may remove the imagery's operational or tactical level application. Knowing this, a worthy adversary

will have devised ways to ensure access to the imagery it needs. The adversary may have created a redundant system of systems that includes strategic and tactical airborne reconnaissance platforms. Another option for the adversary might be to attempt to undermine or negate America's superior technological capabilities by using unfamiliar or different organizational or doctrinal concepts.

The analysis suggests that both space and ground based anti-satellite weapons are less viable in today's multi-polar world. Because of the interdependence of today's space assets, spacecraft attack will in most cases affect multiple actors. An attack may impose upon America's taxpayers high financial liabilities. The debris cloud caused from satellite destruction may unintentionally damage or destroy friendly manned or unmanned spacecraft. Since the adversary may have already procured the database necessary for military operations, spacecraft attack may not accomplish the original objective of denying data. Thus, spacecraft attack may be an ineffective space control measure in many contemporary warfare scenarios. Their use may escalate the conflict, terminate allied support, and eliminate a resource for American military forces. These facts of space attack are often dismissed or forgotten due to the exotic appeal of space attack weapons. These weapons capture warriors' imagination because they represent scientific discovery's latest breakthroughs in harnessing man's destructive capabilities. Additionally, they induce warriors to prepare for their employment because they promise to destroy inanimate objects hundreds of miles from the natural human domain. This promise allows their sponsors to peddle them as the necessary and sufficient space control solution. Such trappings do not take into account the realities of spacecraft attack that become apparent through analysis of weapons effects. Anti-satellite weapons may have been the only

method to achieve space control in the early decades of space exploitation, but they are not as viable in today's information dominated society. Spending vast sums of taxpayer monies to procure Cold War systems for a twenty-first century world may leave America with unusable weapons and ineffective strategy. Space control strategies for the twenty-first century must be based upon more than one option.

The space control mission may be more elusive than in the past, but that does not imply it is beyond America's grasp. The best control measures are those which incur the least amount of risk, cost, and unintended consequences. Reasoned space control for the next century may be limited to terrestrial based activities such as diplomatic bargaining or surgical attacks against certain ground based operations. Precision surgical attack is a capability that the United States military forces excel at with their air, land, and sea-based force application weapons. What is important to remember is that the recommendations the space strategist selects should be based on analysis, rather than on reliance upon Cold War solutions that are still proposed, yet may not be valid. America's achievements in developing the air, land, and sea weapons of industrialized warfare are capable of delivering the temporary space control that she needs for warfare. She does not need to step up to the realm of space warfare to achieve space control.

Proceeding along the space warfare path has several unattractive consequences. It affects arms control agreements and raises questions about world dominance and planetary protection. Although the international system is characterized by anarchy, most nations have agreed to live within the limits of international law and to attempt to resolve differences peacefully. In the early days of space achievement, the major powers rejected the calls of military leaders to use space for terrestrial attacks and the moon as a ballistic

missile base. They agreed to limit military activities in space. Those who advocate departure from these decisions reopen debates on and concern about two important international arms control issues. First, American pursuit of space weapons reduces the effectiveness of current arms control agreements. Second, it jeopardizes her ability to gain additional agreements. Ignoring the problems of arms control may propel the world along the path of lawlessness and violence, moving warfare to yet a higher plateau from which humankind is able to destroy itself.

Turning to the world dominance and planetary protection problems, these two concerns stem from the fact that an entity in charge of space weapons is capable of threatening any spot on the planet. An America in charge of space weapons could be in a position to dominate the world or claim that it is her destiny to become the protector of the planet and its peoples. In either case, an adversary who disagrees with these roles may attack the United States homeland or assets abroad. An entity who does not want America to dominate the world or act as its police force may be encouraged to execute preemptive strikes, perhaps through the use of nuclear, chemical, biological, or genetic weapons. Assuming that America has no designs on planetary domination and that the nations of the world agree that America should police the planet, how might this impact America? In addition to making America a more attractive target for attack, assumption of this role could result in her becoming embroiled in every regional conflict. As America takes this path, other nations may use their resources to pursue national objectives. To gain insight on how this path may develop, consider some of Russia's activities.

Russia holds nearly all of the space achievement records. Russian names normally precede those of Americans in the record books. Their knowledge of space exceeds that

of any other nation. They hold all space endurance records and currently operate the world's only space station. Since the demise of the Soviet Union, Russia has gained access to the world's space markets, including those of the United States. They seek further cooperative space endeavors yet do not protest calls by members of the United States military, industry, or Congress to deploy space weapons. If Congress approves the deployment of American space weapons, Russian space experts could use their space resources for inter-planetary exploration and exploitation. This once again opens the door for them to place their names before those of Americans; they could become the first nation to establish a space colony charged with extracting another planet's precious materials. If America is physically and economically embroiled in solving regional problems, she may even miss the opportunity to tag along as a junior partner in this endeavor.

The space weapons path is not an attractive path for America. As the current generation of warfighters identifies space threats and industry responds with Cold War solutions, both forget that the contemporary world is much different from that in which they spent their formative years. Pursuing space weaponry places arms control agreements at risk, could lead to perceptions that America wants to dominate the planet, and could lead to American assumption of the role of planetary protector. The ability of America's scientists to unlock new destructive capabilities does not necessitate their development or use. Before advocating weapons development or procurement, space strategists must understand the past, present, and future environments and analyze how to achieve the desired objective. Furthermore, the strategist must project the consequences of space procurement decisions. The military space community has not yet emerged from

its Cold War mindset. The challenge for present day space strategists is to redefine its *raison d'être* and the scope of its missions in an intertwined international environment. The twenty-first century will not accept Cold War solutions. The space procurement decisions for the next century must provide a force structure that is based on the challenges of future space operations.

Although intended primarily for space strategists, this work has offered to acquaint non-space operations personnel with some of the complexities and realities of space operations and modern warfare. With a message for present and future strategists, planners, and decision-makers, it has attempted to interject a measure of reality into warfare plans. That reality demands an analysis of effects rather than blind allegiance to exotic weapons and visionless adherence to predetermined employment concepts. For those who immediately leap to destructive methods of coercion, it reminds them of the value of other instruments of power. For those who, unversed in space operations, transfer air and terrestrial warfare concepts to space without understanding the medium nor the consequences of their proposed actions, it offers a more rational approach to decision making. Those who persist at ignoring the differences between air and space or proselytize about the powers of space exploitation without solid historical, experiential, or analytical foundations may be destined to follow in the footsteps of air power theorists who have kept many air strategists' ideas imprisoned in binary thought. Hopefully this work has taken a first step toward avoiding that affliction for America's future space strategists.

This work was accomplished in partial fulfillment of the Masters Degree requirements of the School of Advanced Airpower Studies, Air University, Maxwell AFB, AL, 1996.

Advisor: Major Bruce M. DeBlois, Ph.D.

Reader: Dr Karl Mueller

Notes

- ¹ Jeffrey T. Richelson, *America's Secret Eyes in Space*, New York, 1990, 2.
- ² *Ibid.*, 2.
- ³ *Ibid.*
- ⁴ *Ibid.*, 5.
- ⁵ *Ibid.*, 9.
- ⁶ *Ibid.*, 12.
- ⁷ *Ibid.*
- ⁸ *Ibid.*, 12-13.
- ⁹ *Ibid.*, 13.
- ¹⁰ *Ibid.*, 17.
- ¹¹ *Ibid.*, 26-27.
- ¹² Richelson, *op. cit.*, 19.
- ¹³ According to Jeffrey Richelson, SAMOS did not stand for the commonly referred to Satellite and Missile Observation System. Richelson's sources stated that the WS-117L Project Director selected the name SAMOS in the belief that no one would produce an acronym from it. *Ibid.*, 44.
- ¹⁴ SPOT is the French civil earth observation program *Satellite Probatoire d'Observation de la Terre* operated by SPOT Image Corporation. SPOT Image is headquartered in Toulouse, France. The *Centre National d'Etudes Spatiales* (CNES) is the main contractor for the program. SPOT Image Corporation, CNES, *The Catalogue of SPOT Products and Services*, 1989, 3.
- ¹⁵ SPOT's multi-spectral imagers provide 20 meter resolution data. Wilson, *op. cit.*, 183.
- ¹⁶ The KEYHOLE satellites that continued to exploit the film recovery system included the KH-4A, KH-4B, KH-7, KH-8, and finally, the KH-9 known as "Big Bird". *Ibid.*, 183-184.
- ¹⁷ The major objective of the KH-6 Tallinn mission satellite was to obtain close-look photography of the site near the Estonian city of Tallinn, where 1961 CORONA photographs showed possible anti-ballistic missile deployments. The National Photographic Intelligence Center's interpreters believed that the photos showed construction for the deployment of SA-5 *Gammon* interceptor missiles. Richelson, *op. cit.*, 61.

¹⁸ The data for Figure 1 were derived from Andrew Wilson, *Jane's Space Directory 1994-1995*, Great Britain, 1994, 183-185.

¹⁹ William B. Green, *Digital Image Processing: A Systems Approach*, Second Edition, Moorpark, California, 1989, 2.

²⁰ *Ibid.*, 2-3.

²¹ The Open Skies policy stems from a proposal made by President Eisenhower to Soviet premier Khrushchev at a summit meeting on July 21, 1955. The policy was formally rejected by Khrushchev, but became a de facto agreement as each nation pursued the use of imagery satellites to safely peer into the other. Alvin and Heidi Toffler, *War and Anti-War: Survival at the Dawn of the 21st Century*, Boston, 1993, 230-231.

²² Others argue that the imagery satellites destabilized the strategic nuclear standoff. Because the satellites provide precise targeting data, the superpowers could develop a counterforce vice countervalue nuclear strategy. This was seen as destabilizing because the counterforce strategy encourages preemptive strategic nuclear attack to ensure national survival.

²³ The KH-11 provides eight to twelve images per minute. Andrew Wilson, *Jane's Space Directory 1994-1995*, Great Britain, 1994, 184.

²⁴ For details on the workings of CCD imaging devices see William B. Green, *Digital Image Processing: A Systems Approach, Second Edition*, Moorpark, California, 1989, 37-38.

²⁵ Approximately equivalent to six inches.

²⁶ Wilson, *op. cit.*, 184.

²⁷ Jeffrey T. Richelson, *America's Secret Eyes in Space*, New York, 1990, 126.

²⁸ Using this technology, the KH-11 scans its targets in long, narrow strips and focuses the light onto an array of CCDs with several thousand elements. The light falling on each CCD during a short, fixed period of time is then transformed into a proportional amount of electric charge. In turn, the electrical charge is read off and fed into an amplifier, which converts the current into a whole number between zero and 256. The number represents a shade of color ranging from pure black to pure white. Thus, each picture can be transmitted as a string of numbers, one from each element. *Ibid.*, 128-129.

²⁹ Data collection was limited to only a few hours per day due to power limitations. The power required to transmit the data to the relay satellite was so great that it drained power far faster than it could be replenished by the satellite's solar panels. To increase its effectiveness, the KH-11 operated in concert with the KH-8 and KH-9 until this limitation was solved. *Ibid.*, 134.

³⁰ Stereoscopes allow photo-interpreters to superimpose photos taken from different angles. Such superimposition can yield a three-dimensional effect that makes it easy to determine the height and length of weapons bunkers, space launch vehicles, or other objects of interest. *Ibid.*, 135.

³¹ *Ibid.*, 136.

³² *Ibid.*, 137.

³³ One could argue that America's needs in this area uniquely exceed those of other nations. Being such an open society, it is easy for other nations to acquire data about the United States. Potential adversaries of the United States excel at keeping their societies closed and information about their strategic systems hidden. Thus, one could say that the most sophisticated imagery systems emerged naturally in the United States because 'necessity is the mother of invention'.

³⁴ Wilson, *op. cit.*, 158.

³⁵ To learn more about the national betrayals that occurred in the spy satellite world during the 1970s, see Richelson, *op. cit.*, 157-184; and Robert Lindsay, *The Falcon and the Snowman: A True Story of Friendship and Espionage*, New York, 1979.

³⁶ Richelson, *op. cit.*, 157-158.

³⁷ *Ibid.*, 158.

³⁸ *Ibid.*, 161.

³⁹ Wilson, *op. cit.*, 159.

⁴⁰ Molniya satellites provide government and military communications. They circle the earth in a highly elliptical orbit (commonly referred to as a Molniya orbit) that provides extended dwell time over the northern hemisphere. *Ibid.*; Wilson, *op. cit.*, 154; and Paul B. Stares, *Space and National Security*, Washington, DC, 1987, 209.

⁴¹ One very public example of observation satellites' monitoring value was the nuclear test facility construction site spotted in South Africa by a Soviet satellite in 1977. After intense diplomatic pressure, South Africa dismantled the site. Daniel Deudney, "Unlocking Space," *Foreign Policy*, Winter 1983/84, 95.

⁴² Two factors help set the stage for this transformation: the Air Force's Tactical Exploitation of National Capabilities (AFTENCAP) project and the fall of the former Soviet Union. TENCAP began using the national satellites for tactical operations in the 1980s, but its scope expanded significantly after the Gulf War. After the Gulf War, the Air Force created the Space Warfare Center to give the warfighter direct access to space's bounty. TENCAP was one of the first projects assigned to the SWC and has undergone significant growth since SWC operations began in November 1993. The fall of the Soviet Union changed the international focus from a battle between the superpowers to regional contingencies. While these two factors set the stage for the shift to operational and tactical warfare, it took the Gulf War to hasten the military space community's metamorphosis. For information on TENCAP, see *The Space Tactics Bulletin*, Space Warfare Center, Falcon AFB, CO.

⁴³ Vice Admiral William A. Dougherty, US Navy, "Storm From Space," *Proceedings*, August 1992, 51.

⁴⁴ Guy Durham, "Satellites' Keen Eyes Help Allies See Victory," *Air Force Times*, June 3, 1991, 26.

⁴⁵ Eliot Cohen, *Gulf War Air Power Survey Summary*, March 28, 1993, Air Command and Staff College reprint, Chapter 4, 14.

⁴⁶ Craig Covault, "USAF Urges Greater Use of SPOT Based on Gulf War Experience," *Aviation Week & Space Technology*, July 13, 1992, 63.

⁴⁷ *Ibid.*

⁴⁸ *Ibid.*

⁴⁹ *Ibid.*, 65.

⁵⁰ *Ibid.*, 63.

⁵¹ *Ibid.*, 65.

⁵² General Colin L. Powell, Chairman of the Joint Chiefs of Staff, argued that the intelligence available to the coalition was the best in military history. General Colin L. Powell, *Report on the Roles, Missions, and Functions of the Armed Forces of the United States*, Washington, DC, CJCS, February 1993, 11-13. See also Cohen, *op. cit.*, Chapter 4, 12; and Dougherty, *op. cit.*, 51.

⁵³ Captain Brian Collins, USAF, "Soviet View of the Storm," *Air Force Magazine*, July 1992, 73.

⁵⁴ *Maskirovka* is a Russian term which, loosely translated, means deception.

⁵⁵ Collins, *op. cit.*, 74.

⁵⁶ *Ibid.*

⁵⁷ William Burrows, "Give Space Reconnaissance Systems a B+," *Space News*, August 5-18, 1991, 21; and Cohen, *op. cit.*, Chapters 4, 2 and 15.

⁵⁸ Peter B. deSelding and Andrew Lawler, "SPOT Halts Sales of Gulf Area Imagery," *Space News*, August 13-19, 1990, 3.

⁵⁹ Phillipe Renault, Deputy Director-General of SPOT Image, as quoted in deSelding and Lawler, *op. cit.*, 21.

⁶⁰ deSelding and Lawler, *op. cit.*, 21.

⁶¹ One example of such an occurrence is the controversial images provided on a Libyan chemical weapons plant. The Department of Defense claimed the plant had been destroyed by fire. *Ibid.*

⁶² *Ibid.*

⁶³ *Ibid.*

⁶⁴ *Ibid.*

⁶⁵ Had he been asked to explain warfare, primitive man's task would appear to us to be a rather simple affair. He had few tools with which to work and if warfare involved

anyone other than the two opponents, it may have involved only a few others in a loosely organized group. However, this stretched the limits of his cognitive dexterity. Explaining his form of warfare could have appeared as complex a task as that which humanity undertakes today in trying to understand modern warfare.

⁶⁶ Discussions on other portions of this multi-dimensional interpretation are beyond the scope of this project.

⁶⁷ Many people refer to the Gulf War as the first space war. The author disagrees with this. Space systems were critical in the Gulf War, but to call this the first space war implies that space forces played more than a supporting role. To have a space war, there must be at least two spacefaring entities battling for control of the planet or other resources through the use of terrestrial weapons to attack space objects or space weapons to attack terrestrial or space assets. As of today, all space systems are passive. Thus far, humanity has been successful in curtailing the deployment and employment of space weapons through adherence to treaties such as the Outer Space Treaty of 1967.

⁶⁸ Red mercury, also known as 'cherry red' because of its color, is a semi-liquid compound of pure mercury and mercury antimony oxide. It could be used to make a baseball-sized neutron bomb capable of killing everyone within 600 meters (approximately 0.37 mile) of the explosion. Experts believe this mercury based explosive was developed in the former Soviet Union. "Bomb-Making 'Red Mercury' May Exist After All," *The Military Newswire*, April 28, 1995. See also Britain's *New Scientist*, April 1995.

⁶⁹ The 'system of systems' can be divided into three general categories of reconnaissance assets: space based strategic intelligence assets including DSP and the various types of reconnaissance satellites; strategic airborne reconnaissance assets including RC-135 *Rivet Joint* and U-2/TR-1; and tactical airborne reconnaissance assets including RF-4Cs and unmanned aerial vehicles. Despite the wishes of every warrior, space reconnaissance continues to be limited by weather conditions and orbital mechanics. It is thus unable to provide the continuous imagery coverage required for theater warfare. For the dynamic conditions of theater warfare, strategic intelligence assets will only augment the airborne strategic and tactical reconnaissance platforms that will continue to be the primary providers of timely imagery intelligence.

⁷⁰ As many as 30 countries are currently producing unmanned aerial vehicles.

⁷¹ The SPOT system's technical details are discussed shortly.

⁷² Craig Covault, "USAF Urges Greater Use of SPOT Based on Gulf War Experience," *Aviation Week & Space Technology*, July 13, 1992, 63.

⁷³ Andrew Wilson, *Jane's Space Directory 1994-1995*, Great Britain, 1994, 393.

⁷⁴ *Ibid.*

⁷⁵ Renee Saunders, "War in Iraq Enhances Value of Commercial Remote Sensing," *Space News*, January 21-February 3, 1991, 16.

⁷⁶ Lyn Dutton, David de Garis, Richard Winterton, and Richard Harding, *Military Space*, London, 1990, 99.

⁷⁷ Dutton, de Garis, Winterton, and Harding, *op. cit.*, 98.

⁷⁸ *Ibid.*, 98-99.

⁷⁹ Assessments on the number of entities who will possess military or commercial imagery satellites vary. Some Naval personnel estimate that 15 nations could belong to this group by 2000. In their count, the Navy lists Canada, Germany, Israel, Italy, Pakistan, South Africa, South Korea, Spain, and Taiwan as those expected to have imagery satellites. After 2000, Argentina and Brazil may join the group. Offering a significantly larger estimate, an Air Force Space Command planning directorate report estimates that 30 countries will have reconnaissance capabilities by 2000. See Vincent Kiernan, "War Boosts Anti-Satellite Weapons Proponents," *Space News*, May 6-12, 1991, 7; and Neff Hudson, "Air Force Researching Ground-Based Lasers," *Air Force Times*, May 3, 1993, 3.

⁸⁰ Berner, Lanphier and Associates, "Many Nations Feed Commercial Imagery Market," *Space News*, March 6-12, 1995, 9.

⁸¹ Eliot Cohen, *Gulf War Air Power Survey Summary*, March 27, 1993, Air Command and Staff College reprint, Chapter 7, 21.

⁸² Dutton, de Garis, Winterton, and Harding, *op. cit.*, 98.

⁸³ Patricia A. Gilmartin, "France's SPOT Satellite Images Helped US Air Force Rehearse Gulf War Missions," *Aviation Week & Space Technology*, July 1, 1991, 22.

⁸⁴ William Matthews, "The Digital Warrior," *Air Force Times*, January 6, 1995, 36.

⁸⁵ The process starts with a computer that downloads intelligence data from a satellite. The data, which is processed intelligence, includes information ranging from target area weather reports and terrain features to the latest information on enemy force locations, enemy radars, anti-aircraft missiles, and other threats. Taking this information, the computer produces maps of the intended targets and threats that troops are likely to encounter en route to them. Digital Warrior works through Windows software running on a 486 system. Ultimately, Digital Warrior is intended to provide pilots with computerized maps that will show air crews where they are, where the target is, and where the threats are as the mission progresses. *Ibid.*

⁸⁶ The Navy increased its use of SPOT imagery during and after the Gulf War. Aircraft carriers are now equipped with a SPOT database. Covault, *op. cit.*, 63.

⁸⁷ *Ibid.*, 61.

⁸⁸ *Ibid.*, 63.

⁸⁹ This is not to imply that the use of one type of imagery data precludes use of another. Each clearly has a unique contribution in warfare. For example, in the aftermath of Hussein's scorched earth policy in Kuwait, LANDSAT's broad views guided cleanup crews to oil that remained in the Persian Gulf. At the same time, the high resolution imagery helped estimate the volume of oil in different locations so that necessary

equipment could be on hand. *Ibid.*, 64; and Jay Lowndes, "War's Aftermath Tracked," *Space News*, April 22-28, 1991, 8.

⁹⁰ Captain James R. Wolf, "Implications of Space-Based Observation," *Military Review*, April 1994, 77; and Dutton, de Garis, Winterton, and Harding, *op. cit.*, 96.

⁹¹ In retrospect, some claim that as much as 70 percent of space's assets have tactical value. James M. Gifford and Vincent Kiernan, "Military Calls Space Superiority Essential," *Space News*, May 6-12, 1991, 6.

⁹² Air Force Manual 1-1, *Basic Aerospace Doctrine of the United States Air Force*, AF/XOXWD, March 1992, 10.

⁹³ Joint Publication 3-14, *Joint Doctrine; Tactics, Techniques, and Procedures for Space Operations*, SPJ5X, April 15, 1992, GL-7.

⁹⁴ For the text of the Outer Space Treaty, see United States Arms Control and Disarmament Agency, *Arms Control and Disarmament Agreements*, Washington, DC, Government Printing Office, 1984. See also Sylvia Maureen Williams, "International Law and the Military Uses of Outer Space," *International Relations*, May 1989, 413.

⁹⁵ As recently as March 1995, a senior policy advisor to a Senate Armed Services Committee member said that ASAT capability will be absolutely necessary to protect US troops from being spotted by commercial satellites. This advisor sees the proliferation of commercial imagery satellites as an indication that ASATs are essential and their employment inevitable. "Sharp Imagery Spurs Call for ASAT," *Space News*, March 6-12, 1995, 17.

⁹⁶ Shutter control refers to the government's ability to block sales of imagery from United States commercial satellites. To implement shutter control, current policy requires a Cabinet-level decision during a time of national crisis. Some Congressmen believe this policy is too restrictive and are heading a move to empower officials at lower levels to exercise shutter control. Warren Ferster, "Prospect of Policy Review Rattles Imagery Executives," *Space News*, March 6-12, 1995, 9.

⁹⁷ This lesson is frequently offered to orbital analysts. Several such offerings include the F-15-launched ASAT test, satellite break-ups, and Space Shuttle support operations. The United States' single employment test of its F-15-launched ASAT corroborated the scope of this problem. Orbital analysts assigned to the Space Surveillance Center within a few years of that test are fully aware of the protracted challenge of identifying and tracking those hundreds of pieces of debris. Every time an on-orbit satellite breaks up, the challenge begins anew. For orbital analysts charged with the responsibility of Space Shuttle safety, what was once an infrequent notification requirement has nearly become a full-time job. As the set of orbital objects grows, so does the threat to spacecraft.

The scope of this problem significantly increases when considering the limitations of America's space surveillance network. The majority of the space surveillance sensors are only capable of tracking objects that have a radar cross section of 10 centimeters or larger. The network daily tracks approximately 7000 such objects; however, the complete

set of orbital objects is much larger than this. Using data derived from some of the network's more sensitive sensors, analysts estimate that there are between 60,000 and 1,000,000 pieces of orbital debris ranging in size from one to 10 centimeters. Debris objects smaller than one centimeter are estimated to number around the billion mark. The combined efforts of spacecraft shielding and collision avoidance notifications provide some protection for the Space Shuttle. However, as the 20,000 craters discovered on the Long Duration Exposure Facility after 69 months on orbit indicate, space is a hostile environment. Knowingly taking actions that exacerbate the debris problem places both adversarial and friendly spacecraft at higher risk.

⁹⁸ One could argue that destruction of a launch facility is necessary when the adversary is preparing to launch an ASAT attack. This unique circumstance would, of course, modify the assumption that one is dealing with an on-orbit system and subsequently modify the conclusions. The author, in offering the analysis is not attempting to include all possible scenarios or variables, but rather to disclose a reasoned approach to space control decision-making.

⁹⁹ There are currently only 20 spaceports: five in the United States, three in the former Soviet Union, three in China, two in Japan, and one each in France, Italy, Australia, French Guiana, India, Israel, and Brazil. Andrew Wilson, *Jane's Space Directory 1994-1995*, Great Britain, 1994, 431.

¹⁰⁰ These statements should not be construed as a rationale for the creation of a Joint Forces Space Component Commander, but rather as an argument that America's space systems have evolved to the point at which only space systems personnel should be granted authority and responsibility for leadership of space forces.

The move to create a Joint Forces Space Component Commander transfers from Desert Storm the image of the Joint Forces Air Component Commander who was responsible for coordinating all air operations. The contemporary JFSCC concept is titillating to those who seek position and power, but there is no need for it. The global nature of space systems allows for their centralized command and control from within the United States borders at the hands of USCINCSpace. The majority of military space assets continue to provide the data they were designed for, namely, strategic intelligence and warning. The space systems that provide tactical data within a theater of operations can be commanded by a field grade officer reporting operationally to the theater CINC and administratively to the respective space command. If America's military forces were to reorganize themselves in a manner similar to that chosen by the Russians, that is, a military that includes a Space Force and reconnaissance-strike organizational concepts, plus deployment of space weapons, perhaps it would be time to create such a position. Until America's space forces have evolved to the point where it plays an active role in force application, a JFSCC is unnecessary.

Regarding the leadership responsibilities for space forces, only a person with space systems experience is fully qualified to lead space forces. This follows the exact same reasoning that has been used since the inception of America's independent Air Force to justify that its leadership be restricted to its small set of rated personnel. Air and space are

uniquely different media, just as are land, sea, and air. The contributions space systems give to warfare are similarly unique. Just as a much shorter period of time was sufficient to provide justification for the argument that only airmen lead air forces, forty years of evolutionary history is sufficient to justify that only space systems personnel lead space forces.

America's four decades of military space exploitation has created a large pool of space experts from which to groom and summon the future's space leaders. Many possess the cognitive faculties as well as other critical leadership traits; what they may lack is training in the art of warfare. This is a systemic problem that can be overcome.

Injecting rated personnel into space leadership positions only serves to offer auxiliary leadership opportunities to potential air leaders. Concurrently, this hinders the development of future space strategists and leaders who do not gain the experience offered through those leadership positions. This can also impact their selection for subsequent advanced educational and leadership opportunities. Due to their lack of experience with space systems, the rated personnel are placed in the unenviable situation of being responsible for decisions about an unfamiliar medium. In most cases, they do not understand the nature of the United States military's role in space, the military space community or its unique sub-communities, or the educational and technical requirements of its people. The level at which this problem exists is obviated by Space Command's 400 percent over-manning level for rated officers and its continued ability to hire rated personnel with no space experience to take critical leadership positions. The difficult situation that the Air Force's leadership faces is that it needs the warrior mentality it has given to its top rated officers yet needs those warriors to have space systems expertise. The solution to this dilemma is a concerted effort on the part of Air Force leaders to: (1) immediately and significantly reduce the number of rated officers in its space commands, (2) open more space systems positions at its warrior training schools, and (3) reserve its space leadership positions for those with space systems expertise. Failing this will perpetuate many of the problems that have stymied the maturation of military space doctrine, policy, and strategy during America's first forty years of military space activity.

Russian space achievements include the majority of firsts: they were the first to place a satellite in orbit; place men and women in orbit; leave orbiting crafts to walk in space; send human artifacts to another planet (Venus); flyby, impact, circle, and orbit a craft around the moon; conduct welding and smelting experiments in space; place an automated lunar rover on the moon; place a space station on-orbit; and land spacecraft on Mars. They hold the human endurance records, have the most expertise in scientific investigation, and currently maintain the only space station. In addition to these firsts, one of their most recent achievements was the formation of an independent Space Force. America also has a few space firsts including the first test of an ASAT weapon (1959), the first and only men to explore the moon, and the first spacecraft to land like a plane. America may not be as ready as Russia to form an independent Space Force, but there may come a day when it is the correct decision. In preparation for that day, the Air Force should begin now to wean itself from its reliance upon rated personnel for space leadership. Deferring this decision helps neither the military space mission nor its potential

space forces leaders. It will serve America well to groom its space experts for space leadership rather than allowing those without space experience to lead American forces into the next century.

To learn more about Russian concepts, see Mary C. FitzGerald, "The Soviet Image of Future War: 'Through the Prism of the Gulf War,'" Hudson Institute HI-4145, May 1991; Mary C. FitzGerald, "The Soviet Military and the New 'Technological Operation' in the Gulf," *Naval War College Review*, Autumn 1991, 16-43; Mary C. FitzGerald, "Russian Views on Electronic Signals and Information Warfare," *American Intelligence Journal*, Spring/Summer 1994, 81-87; Mary C. FitzGerald, "The Russian Military's Strategy for 'Sixth Generation' Warfare," *Orbis*, Summer 1994, 457-476; and Benjamin S. Lambeth, "Desert Storm and Its Meaning: The View From Moscow," RAND R-4164-AF, Santa Monica, CA, 1992. To learn more about America's first ASAT weapon, the *Bold Orion*, see Andrew Wilson, *Jane's Space Directory 1994-1995*, Great Britain, 1994, 163; and Paul B. Stares, "Deja vu: The ASAT Debate in Historical Context," *Arms Control Today*, December 1983, 2-3.

¹⁰¹ The primary sources for the SPOT technical data that follows are William B. Green, *Digital Image Processing: A Systems Approach, Second Edition*, Moorpark, California, 1989, 46-49, and Andrew Wilson, *Jane's Space Directory 1994-1995*, Great Britain, 1994, 392-394.

¹⁰² Even during the Cold War, SPOT Image Corporation advertised its intelligence gathering capabilities and military usefulness through its advertisement entitled "The New Way to Win!". "SPOT: The New Way to Win" advertisement, *Defense Electronics*, November 1988, 68.

¹⁰³ Approximately 500 miles.

¹⁰⁴ SPOT's high resolution visible sensors use the push broom scanning technique that utilize a linear CCD as the active sensor. The camera optics focus the full width of the ground swath onto the CCD array as the spacecraft travels along its orbital path. The CCD is sampled at a specific frequency to provide sequential lines of image data. Beamsplitters transfer image data to the spectral CCD detectors to acquire multi-spectral imagery.

¹⁰⁵ The twin imagers can operate independent of each other, in panchromatic or multi-spectral modes, and at near vertical or variable angles. Each imager can be steered to any of 91 orientations 0.6 degree apart. This results in a capability for a plus or minus 27 degree off nadir view and the ability to view a single area on seven successive passes. SPOT is thus capable of stereo imaging and re-attempts when observations are hampered by cloud cover. The oblique viewing capability decreases the actual revisit time from 28 days to effectively 3.7 or 2.4 days depending on where the targeted imaging area is located on earth. The ground swath width is 60 kilometers for the panchromatic imagery and 117 kilometers for the multi-spectral imagery. A SPOT scene will range from 60 kilometer square for a vertical view angle to a 60 kilometer by 80 kilometer maximum at a 27 degree viewing angle (the maximum viewing angle).

¹⁰⁶ Conversion of unidirectional current.

¹⁰⁷ Level 1 is basic radiometric and geometric corrections. Level 1A is essentially raw data and is useful for stereoplotting and basic radiometric studies. Level 1B is full radiometric and limited geometric corrections and is the basic pre-processing level for photo interpretation and thematic analysis. Stereoscopic pairs data are also available at this level. Level 2 provides rectifications according to a given cartographic projection. Level 2A corresponds to Level 2 precision processing but can be implemented without use of map ground control points. Level S scene verification is based on ground control points, ensuring registration with another scene used as a reference to within 0.5 pixels. Level 1AP was introduced in 1990 and is optimized for photogrammetric applications using analytical stereoplotters. Wilson, *op. cit.*, 393.

¹⁰⁸ The proposed SDRS at Fucino, Italy, is still under negotiation. Wilson, *Ibid.*.

¹⁰⁹ The data for Table 4 were derived from Wilson, *op. cit.*, 393.

¹¹⁰ Peter B. deSelding and Andrew Lawler, "SPOT Halts Sales of Gulf Area Imagery," *Space News*, August 13-19, 1990, 3.

¹¹¹ Figure 4 is based on information contained in Wilson, *op. cit.*, 393.

BIBLIOGRAPHY

- Burrows, William. "Give Space Reconnaissance Systems a B+," *Space News*, August 5-18, 1991.
- Cohen, Eliot. *Gulf War Air Power Survey Summary*, Washington, DC, 1993.
- Collins, Captain Brian, USAF. "Soviet View of Storm," *Air Force Magazine*, July 1992.
- Covault, Craig. "USAF Urges Greater Use of SPOT Based on Gulf War Experience," *Aviation Week & Space Technology*, July 13, 1992.
- deSelding, Peter B. "Gulf War Spurs Call for European Spy Satellites," *Space News*, March 11-17, 1991.
- deSelding, Peter B. and Andrew Lawler. "SPOT Halts Sales of Gulf Area Imagery," *Space News*, August 13-19, 1990.
- Deudney, Daniel. "Unlocking Space," *Foreign Policy*, Winter 1983/84.
- Dougherty, Vice Admiral William A, USN. "Storm From Space," *Proceedings*, August 1992.
- Durham, Guy. "Satellites' Keen Eyes Help Allies See Victory," *Air Force Times*, June 3, 1991.
- Dutton, Lyn, David de Garis, Richard Winterton, and Richard Harding. *Military Space*, London, England, 1990.
- Ferster, Warren. "Prospect of Policy Review Rattles Imagery Executives," *Space News*, March 6-12, 1995, 9.
- FitzGerald, Mary C. "The Soviet Image of Future War: 'Through the Prism of the Gulf War,'" Hudson Institute HI-4145, May 1991.
- FitzGerald, Mary C. "The Soviet Military and the New 'Technological Operation' in the Gulf," *Naval War College Review*, Autumn 1991, 16-43.
- FitzGerald, Mary C. "Russian Views on Electronic Signals and Information Warfare," *American Intelligence Journal*, Spring/Summer 1994, 81-87.
- FitzGerald, Mary C. "The Russian Military's Strategy for 'Sixth Generation' Warfare," *Orbis*, Summer 1994, 457-476.
- Gifford, James M. and Vincent Kiernan. "Military Calls Space Superiority Essential," *Space News*, May 6-12, 1991.
- Gilmartin, Patricia A. "France's SPOT Satellite Images helped US Air Force Rehearse Gulf War Missions," *Aviation Week & Space Technology*, July 1, 1991.
- Green, William B. *Digital Image Processing: A Systems Approach*, Second Edition, Moorpark, California, 1989.
- Hough, Harold. "Eyes in the Sky: Satellite Surveillance for the Masses," *Soldier of Fortune*, May 1991.

- Hudson, Neff. "Air Force Researching Ground-Based Laser," *Air Force Times*, May 3, 1993.
- Kiernan, Vincent. "War Boosts Anti-Satellite Weapons Proponents," *Space News*, May 6-12, 1991.
- Lambeth, Benjamin S. "Desert Storm and Its Meaning: The View From Moscow," RAND R-4164-AF, Santa Monica, CA, 1992.
- Lowndes, Jay. "War's Aftermath Tracked," *Space News*, April 22-28, 1991.
- Matthews, William. "The Digital Warrior," *Air Force Times*, January 6, 1995.
- The Military Newswire*, April 28, 1995.
- O'Sullivan, Kate. *The I-Bomb*, London, England, 1995.
- Pelton, Joseph N. *Future View: Communications Technology and Society in the 21st Century*, Boulder, CO, 1992.
- Powell, General Colin L., USA. *Report on the Roles, Missions, and Functions of the Armed Forces of the United States*, Washington, DC, CJCS, February 1993.
- Richelson, Jeffrey T. *America's Secret Eyes in Space*, New York, 1990.
- Richelson, Jeffrey T. "Implications for Nations Without Space-Based Intelligence Collection Capabilities," in *Commercial Observations Satellites and International Security*, edited by Michael Krepon, et al, New York, 1990.
- Saunders, Renee. "War in Iraq Enhances Value of Commercial Remote Sensing," *Space News*, January 21-February 3, 1991.
- SPOT Image Corporation, CNES. *The Catalogue of SPOT Products and Services*, 1989.
- SPOT Image Corporation, CNES. "SPOT: The New Way to Win!" advertisement, *Defense Electronics*, November 1988, 68.
- Stares, Paul B. "Deja vu: The ASAT Debate in Historical Context," *Arms Control Today*, December 1983, 2-3.
- Toffler, Alvin and Heidi. *War and Anti-War: Survival at the Dawn of the 21st Century*, Boston, MA, 1993.
- United States Air Force. *Air Force Manual 1-1, Basic Aerospace Doctrine of the United States Air Force*, March 1992.
- United States Air Force. *The Space Tactics Bulletin*, Space Warfare Center, Falcon AFB, CO.
- United States Arms Control and Disarmament Agency. *Arms Control and Disarmament Agreements*, Washington, DC, Government Printing Office, 1984.
- United States Space Command. *Joint Publication 3-14, Joint Doctrine; Tactics, Techniques, and Procedures for Space Operations*, April 15, 1992.
- Wickham, General John A., Jr., USA (Retired). "The Intelligence Role in Desert Storm," *Signal*, April 1991.

- Williams, Sylvia Maureen. "International Law and the Military Uses of Outer Space," *International Relations*, May 1989.
- Wilson, Andrew. *Jane s Space Directory 1994-1995*, Great Britain, 1994.
- Wolf, Captain James R. "Implications of Space-Based Observation," *Military Review*, April 1994.